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Protected Viticulture for Sustainable Grape Production to Cope with the Adverse Effects of Climate Change

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Abstract

Grapes (Vitis vinifera L.) are among the most commonly cultivated horticultural crops on the earth covering an area of 7.5 million hectares with around 70 million tons production. Grapes being highly nutritious are majorly utilized in making beverages or used as fresh and raisin. In today's world, the most concerned topic in agriculture is continuous change in climatic conditions leading to several negative social, ecological, economical and biological problems. Grapes are delicate fruits, their vines are sensitive towards extremes in temperature, water, heat, duration and intensity of light exposure as well as carbon dioxide and humidity alterations. Hence, one can shift to drought and heat tolerant varieties and certain training and pruning methods suitable to the prevailing environmental conditions. Vineyard management practices, including farm mechanization can be amended for improving the gains, while reducing the input. Control over temperature and proper water supply are needed to help the vines against stress. Wind machines in areas facing speedy, chilling winds mix the cold and warm air, reducing the freezing injuries to plants. An old method is to cover the young plant with soil mound to conserve the heat but this can expose the plant to microbes, causing vine rots and damaging their fragile roots. In areas where summer heat is insufficient for conversion of vegetative buds into reproductive ones, it is needed to conserve the heat by covering plants with some insulator like polyethylene sheets. Mulch is also used to conserve soil moisture in drylands. Also, certain organic amendments can protect the plant from under-nutrition. Climate change renders the plants more sensitive for certain disorders so we use some pesticides or growth promoters to counteract those abnormalities. The best approach is to combine all the environment-friendly sustainable strategies and apply a joint integrated crop management (ICM) approach for successful viticulture.

Keywords: Viticulture; climate change; protected agriculture; environmental stress factors

Introduction

Grapes are among the most cultivated fruits on earth covering an area of 7 and a half million hectares with around 70 million tons production [1]. Grapevine, scientifically known as Vitis vinifera L. is the most widely cultivated specie among the 70 members of Vitaceae family [2]. Cultivation of grapes started around 7000 years back in South Caucasus [3] and now grapevines are cultivated in more than 60 countries on a commercial scale. The leading producers are Europe, north parts of America and some Asiatic countries however they can be grown in all temperate climates especially Mediterranean areas [4]. DNA studies of fossil fuels confirms that grapes were brought to Mediterranean region via Greece [5].

Grapes are highly nutritious and are majorly utilized in making beverages, in addition to their consumption as fresh and dried fruits [6]. In the past years, only locally available genotypes were exploited but with the advancement in knowledge and growing needs of human beings, exotic grape cultivation started after mid of 19th century, in pursuit of enhancing production, taste and effective pollination [7]. Another highly appreciable trait in grapevines is their tolerance against biotic and abiotic stresses specially drought stress [8].

Grapes are known for their extensive adaptability in different climatic zones. The natural grape zone is supposed to be temperate with average temperature ranging between 10 and 20 ^{0}C with a daily average requirement of 14 ^{0}C during growing season. A total of 2500 ^{0}C heat accumulation is required during active growth for induction of flowering and fruit production while the daily maximum permittable temperature is 17 ^{0}C [9]. Lately, they have been cultivated successfully in tropical areas but the main constraints of viticulture in tropical areas is extremely high temperature, not enough cold hours in winter and the shortage of water. Warm weather can induce irregular opening of buds but at the same time increase the quality of fruit and its products like wine. Nevertheless, if suitable varieties are grown, enough water is supplied on proper time and plants are maintained with care, they can produce a bumper crop even in tropical regions or under adverse changing climatic conditions [10, 11].

Climate change is a serious threat for the survival of all living beings on the face of earth [12]. Viticulture is affected negatively due to climatic changes perhaps more than some other fruits. In the agricultural sector, the management practices, varieties and cultivation methods are modified often, in order to adapt to the changing habitat properties [13, 14]. There are so many studies performed to find the best solution for changing climate and to make plants more tolerant and productive in their continuously changing habitats [15].

Grapes have always been a subject of interest in the studies of climatic changes, socioeconomics and globalization [16]. The adaptation of a suitable method is dependent on many factors and a single strategy cannot be hold right for all systems and climatic zones. Even in the same climatic zone, we need to adopt different methods of raising and training vines according to the available capital and techniques [17]. Vineyards are highly sensitive to their micro and meso-climates, thus, for gaining a successful crop from vines, their climatic needs cannot be neglected [18]. Besides climatic requirements, vineyards also require specific soil chemistry and physical structure for showing their full potential in terms of large size juicy berries [19, 20].

Even under the best growing conditions, grapevines need timely and proper pruning, training, pinching, girdling, topping, thinning and grafting techniques. The concept was introduced by OIV (Resolution OIV/VITI 333/2010) under the term Terroir which refers to the complete set of proper soil, climate, biodiversity, management practices and cultural activities demanded by a plant for its beneficial and economical commercial production [21]. Grape vines require a minimum of 10 ^{0}C temperature to induce fresh growth (Bonada and Sadras, 2015) and change in the immediate environment can cause delayed fruiting or early ripening. This disturbance in the growth pattern reduces the wine quality and market value of table fruits (Fraga et al., 2014). The Growing Degree Units Index is inevitable for defining the quality and quantity of the grape yield [22] and to discover the exact needs of the plant, the best choice is to grow them under different climatic conditions and then study their behavior of productivity and growth [23]. It will also demonstrates the adaptability of plants under diverse climatic habitats. For instance, vines from Portugal are bet-

ter adapted to dry and hot climates [24].

Agriculture is the most vulnerable sector to the change in climate as all the plants have their own particular heat, light, humidity and water requirements. In order to nullify the harmful effects of climatic changes, some steps are supposed to be taken. These steps are collectively termed as "Climate Change Adaptations" [25]. For delicate fruits like grapes, these steps must be continuously followed from the time of planting the vineyard till the sale of fruits and even after sale, for storage of fruits [17]. According to a study, due to global warming, grape vines face almost 4 days delay in shifting from vegetative to reproductive stage after each 10 years. Also, due to scarcity of water, production has been compromised lately both in terms of weight and excellence of the fruit [26]. Additionally with the increase in concentration of carbon dioxide in the air, grape berries accumulate more dry matter and become less juicy [27]. However, water scarcity is by far the most threatening problem for grape cultivation [28].

For solving water deficiency issue, practices including deficit irrigation, partial root-zone drying, fruit thinning, timely pruning of plant, water re-use, selection of drought resistant varieties and even shifting of vineyards towards hilly areas have been suggested [29-31]. Any one approach for dealing with this serious issue cannot be enough so we have to integrate these approaches and develop a combined technology for successful viticulture [32].

Climate Change

In today's world, the most concerned topic is continuous change in climatic conditions leading to several negative social, ecological, economical and biological problems [33-35]. As the agricultural sector solely depends upon both biotic and abiotic factors of environment, it is seriously affected by slight changes in climate and even the flora of the surroundings [36, 37]. However, some of the crops are affected more than others due to higher sensitivity to changes in environment. Horticultural crops, including grape vines are more prone to the damages of climatic changes as they are long-lasting plants and remain in field for several years [32, 38]. The best way to combat against climatic change is to choose cultivars that can easily adapt to change in climate, without compromising on the quality and amount of the production, as we cannot change the plants every year. There are also certain cultural practices and growing techniques that should be adopted to gain maximum potential of the plants [39-41].

Grapes are delicate fruits and vines are highly sensitive to changes in air temperature and humidity, which have direct effect on the duration of vegetative and reproductive period of vine, pathogenic attack and also the quality of fruit and its products. For illustration, grape fruits ripe early under high temperature but due to insufficient time of maturity, the chemical constitutes of fruits are not able to develop fully, causing tartness in taste and reduction in their market value [20, 42, 43]. Some scientists have suggested that the production areas of grapes should be relocated according to the climatic requirements of the vines and different varieties should be studied under different climatic zones to find the best location and best adaptable variety under ever changing climatic conditions [44, 45]. However, it is not as simple to adopt as it seems in mind because of the certain traditional, social, psychological and monetarily barriers [46, 47]. Some of the farmers lack knowledge about adopting new technology Even if they realize the changes in environment and try to modify their conventional techniques, most of the time, they lack enough capital to afford the latest method [48, 49]. The success of viticulture in ever changing climatic conditions is also dependent on the previous land history, surrounding neighboring crops and their physical conditions, history of pest attack in that area and even on the societies of human in nearby areas [50-54].

Any change in the normal weather and climate of a place that has existed for a long time is termed as Climate Change. In the present age, it is the biggest threat to living things on earth [27]. The most affected part of climate is temperature which is continuously increasing and leading to other problems like water shortage, energy imbalance in environment and risky climatic events including unpredicted rainfalls, hurricanes and harsh winds at unexpected times and in unnatural areas [27, 55]. Besides all the negative social, economic and environmental destructions caused by climate change, the most affected area is agriculture because agriculture depends directly on the prevailing climatic conditions. Temperature, wind velocity, humidity in the air and water supply are

the key governing sections of agricultural productivity, especially in the case of sensitive crops like grapevines. The problem is more serious in the cold areas like Europe and the areas in its vicinity because grapes grown there are not used to harsh hot weather and the countries are continuously facing temperature rise of minimum 2 ^{0}C each year since 2004 [56].

Viticulture is overly disturbed due to the change of climate as this crop is mostly grown in the Mediterranean region for fresh or dried fruits and also for extraction of high-quality wine. In extreme weather conditions, the nutraceutical properties of fruits and quality of extracted wine reduces thus diminishing the market value of crop [32, 38, 57-59]. The Mediterranean climate is considered as the best for production of grapes and the quality of viticulture here is unmatched anywhere in the world but the changing weather conditions are causing their decline. Due to the reduction of product value, viticulture area is shrinking in most cold parts of the world but the market demand is increasing exponentially [60].

Climate Change and its Effect on Grapevines

As the grapevines are in the field for almost half a century, thus they witness a lot of weather changes, sometimes they also adapt to the change in climate and other times they can be a failure. Also, it is widely accepted by the scientific community that viticulture production is more sensitive to climatic changes as compared to changes in the growing media or soil or even the variety of the plant [61]. Among the yield defining abiotic parameters of viticulture, water availability in right amount and at right time and specific temperature during different growth stages are most critical factors [62]. Grapes are really gentle fruits with extreme sensitivity towards the cold temperature required for plant establishment and inducing flowering and fruiting while on the other hand, a particular hot span is undeniable for fruit ripening and flavor development. Frost is also critical in viticulture [63].

With the increases in heat, fruit size and antioxidant content of fruit decrease but at the same time, increment in basicity and juice content was observed. Fruit flavor, peel color, hue and aroma are also dependent on the prevailing temperature conditions and water availability to plant [64-66]. The vegetative growth of vine occurs generously above 20 ^{0}C but below 35 ^{0}C, however, for vegetative bud induction, a minimum 10 ^{0}C temperature can trigger the response. This temperature also helps in accumulation of food reserves in vegetative parts of plant for next bloom [67]. If the temperature goes above 35 ^{0}C, even the vegetative growth and activities cease; sometimes causing sunburn and other severe heat injuries to the vines that can cause reduction or stoppage of photosynthesis leading to the death of the plant [68]. Fruit ripening is triggered by high temperature and if the fruit has not matured physiologically but it ripens due to excessive heat, its taste and table life will be negatively affected [69-71].

The lowest temperature tolerated by grapevines differ with the variety, other microclimatic conditions and orchard management practices but the tolerable range exists between -20 ^{0}C to -5 ^{0}C without getting chilling or frost injuries [72]. Similar to heat damage, viticulture is also sensitive towards freezing temperatures specially just before the onset of summer. This cool span can cause delay in bud opening and conversion of vegetative buds into flowering buds, that indirectly delay veraison and thus at the time of harvest, fruits have not yet developed proper nutrients and ripening stage. It disturbs the whole crop cycle of grapes. From the mentioned facts, it can be deduced that temperature is the prime factor for defining the growth stage and its duration for grapevines [61].

Besides temperature, total volume of annual rainfall and time of rainfall are also very important in viticulture because grape vines are very specific about their water needs. Rainfall is more crucial if the area is rainfed and there is no other source for soil moisture [73-75]. During the vegetative flush growth, moist soils are required but once the flower buds break, dry soils are demanded until the fruits are ripened. If the wet or moist soils persist even in reproductive stage and during fruit ripening, fruit quality is compromised. Due to less accumulation of sugar, fruits become more watery and will not mature on time [76]. Also, vegetative growth will not stop if there's still moisture in soil and hence vine become giant in size, without producing enough fruits and of course, hard to manage [77]. An unnecessary supply of water causes the vines to droop and become lanky. Moist conditions also trigger fungal and microbial attacks. If there are extra rains or over water application in summer, it can postpone the reproductive stage

and can also kill the flowering buds [76]. Thus, a dried spell is obligatory in vintage areas [78].

Grapevines can resist shortage of water but if a heavy water application is followed by long dry span, it can be detrimental to the vineyard, particularly if the vines are young and in their vegetative stage [79, 80]. The problem can be more severe if rain is the primary source of irrigation, due to uncertainty of rainfall timings and amount [81]. Due to the less or untimely water application, photosynthesis is affected due to stomatal closing, causing low food deposition in the plant, stunted growth, small fruit size and overall low productivity from the vineyard [82-84]. According to scientific surveys, growth of grape plants is most negatively affected when enough water is not supplied [85, 86]. Although, sometimes, water supply is deliberately controlled and reduced in order to increase concentration of tannins, procyanidin, other antioxidants, malic acid and anthocyanins [82, 87].

Another factor important in viticulture is sunlight intensity and duration for which vines are exposed to heat [88]. The relation of fruit quality with light availability is very complex because light is indirectly related to temperature but individual effect of both factors is totally different. Like in case of fruit's biochemical composition, high temperature reduces the anthocyanin content in fruit but longer exposure to light or high light intensity leads to accumulation of anthocyanins. Due to such confusions, the effects of temperature and light are not easily understood separately. Likewise, higher intensity of light leads to higher photosynthetic rates and increased opening of stomata but at the same time can increase the risk of heavy sunburn [61].

Carbon dioxide is the main ingredient of food preparation by the plant; thus, we can say that more carbon dioxide means more yield. However, just like the case of light, it is also connected with rise of temperature and when the individual effect of carbon dioxide is required to be known, an irregular fashion in the growth and production of grapevines is observed due to overcasting effect of temperature [62]. Broadly speaking, grapes are relatively resistant to changes in the climate but instant extreme change in the vicinity can lead to serious nonreversible damages. Vines are especially non-tolerant to snowfall and frost injuries in their non-productive stages. At the same time, hot winds can also destroy the physiological cycle of plant [58].

Until the end of the last century, it was considered that climate change is not serious except the yearly variations but in the last decade of preceding century, the negative effects of climate change over grapevines were first realized in Europe. Since the start of 21st century, climate change has been a hot debate specially for viticulture, as a result of that, a large number of researchers in France join hands to study the effects of climate change on viticulture and the solutions for vineyard's sustainable productivity [89]. Many researches have been performed for finding adaptations against the mentioned problems directly or indirectly [17, 90].

Evaluation of Effects of Climate Change on Vineyards

For managing a vineyard successfully, we need to have a detailed record of already prevailing and expected conditions of temperature, humidity, precipitation and other abiotic factors of environment in that particular locality [91]. Even the comprehensive data on the maximum, the minimum and average temperatures occurring daily, monthly and yearly is not enough and we have to also consider the biotic factors of microclimate [92]. For abiotic climate estimation commonly used methods are Huglin Index, Cool Night Index, Winkler Index, Growing Degree-Days Index and Mean Growing Season Temperature. Temperature measurement is also done by counting number of days during growing season or annually, having more than 30 ^{0}C temperature [78].

In order to estimate the effect of climate change on vineyard or any other plant, first of all we need to estimate the amount or extent of expected change in climate of the vicinity. For that purpose, there are certain Global Climate Models whose results are proportionated according to the crop and region under study with the help of Crop Simulation Model and Regional Climate Models [93-98]. Global Climate Models, designed by Intergovernmental Panel on Climate Change have predicted the possible emitted amounts of chlorofluorocarbons, carbon dioxide and other gases not considered friendly for environment. The estimates cover all the emissions expected to occur till the end oof this century [99]. During the last 10-15 years, studies on Regional Climate Models have been accelerated due to the rapid and challenging changes in crop behavior of grapes with respect to climatic changes [61].

When planning a sustainable vineyard, the first thing to consider is the possible climatic change that can be expected in near future as well as in long run. As climate is a complex term and it contains so many parameters that it is nearly impossible to have an exact estimate of it. However, an idea can be derived from the emission of carbon dioxide, chloro-fluro-carbons and other greenhouse gases and along with it the specific conditions persisting in that particular locality also needed to be considered [100-102]. After a series of experiments a 2 ^{0}C rise of temperature and 50% reduction in precipitation was recorded for future. Such experiments are needed to be repeated again and again due to the continuously changing nature of environment but if experiments are performed under controlled conditions, then data can be collected comparatively easily [25]. While estimating climatic changes in general, day to day variations in climate cannot be neglected and the general estimates must be drawn down to extract data for microclimates also. It will help in adapting some native techniques in order to combat the forecasted changes in climate [51, 103].

Sustainable Grape Production

As the climate is constantly changing, of course not in favor of many crops, thus we need to devise other strategies to maximize the yield and fulfil the demands of food for mankind and other animals. In the current scenario of vineyards, we can shift towards the varieties more tolerant to drought and heat stress. In order to get a higher number of adaptable plants in short time, we can use cloning or go for grafting technique [21, 104, 105]. We can also adapt certain training and pruning methods more suited to the prevailing environmental conditions. Vineyard management practices, including farm mechanization are also needed to be amended for improving the gains, while reducing the input. Grapevines give generous production when supplied with ample amount of nitrogenous fertilizer and water with persistent hot conditions to ensure enough stomatal opening. If such conditions are not found naturally we can aid the vineyard with fertigation [35]. In order to get more healthy and tasty berries their size must be balanced by checking the amount of nitrogen applied keenly [106, 107].

There is also a need for artificial control over temperature of the area because unbalanced temperature can degrade grape quality. Green colored berries with tart taste are illustrated when temperature is very low and berries become too much sugary with unpleasant smell under elevated temperature [108]. If the grapes are grown for wine extraction, the best quality juice content with perfect sweetness and just the right aroma are produced if mild temperature exists between Sep.-Oct. in N-hemisphere and between March-April in S-hemisphere [109]. At certain stages of fruit development, vineyards need to be stressed for enhancing biochemical composition of fruits like antioxidants [110] and aromatic compounds [111, 112]. An interesting aspect of climate change is that it is not always an evil thing. Because with the shift of temperature, viticulture has been adopted in some strange areas where long before, due to cool summers, there was no possibility for vineyards [17]. There are a lot of reports of growing grapes in so-called outlandish areas round the world. However, the success of these vineyards will be determined with time when actual produce from these orchards will be compared with their commercial counterparts. Biotic interactions are so complex that any clear conclusion cannot be drawn based roughly on models, until and unless we get the real harvest at hand to actually measure the outcomes [113].

High percentage of carbon dioxide in the orchard means high temperature which not only favors the rate of food production by plants but also controls the amount of moisture by transpiration. If water supply to the soil is controlled, we can even control the fauna there and some of the microbes can be helpful in survival of vines against water stress [114]. Consequently, detailed and comprehensive literature both in terms of external and internal factors, even genetics is the need of hour for successful viticulture [115].

Protected Viticulture

Commercial vineyards are delicate in terms of facing harsh environmental conditions and they need certain modifications in their environment to keep them safe from severe winds, unnecessary rainfall and scorching heat of sun.

Protection of Newly Transplanted Vines

The fledgling and subtle vines are not able to resist the extreme cold condition of prevailing air and some tactics need to be adopted in order to rescue them from punitive damages. An old method is to cover the young plant with soil mound to conserve the heat around baby plant but this can expose the plant to microbes in the soil and can lead towards rotting of vine, in addition to damaging its fragile roots. To solve this issue, we can use sawdust cover, cardboard boxes filled with wood shavings, polyester foam or even just air-filled boxes of corrugated fiber providing 1-5 ^{0}C increase in temperature, depending upon the material used. During cold nights a difference of 4 ^{0}C and during days 6 ^{0}C temperature raise is enough to keep the plants safe from frost injuries. Sawdust is proved to be the warmest media but can also kill some flowering buds before opening [116].

Polyethylene Covers Over Individual Plants

There are some grape-growing areas around the giant water bodies whose summer is insufficient to provide required heat for conversion of vegetative buds into reproductive ones and even if those vines bear fruit, their taste is tangy and lacking in sweetness, in short, not acceptable by either table consumer or wine industry. In those areas we need to conserve the day heat by covering plants with some insulator like polyethylene sheets. Vines are covered by these sheets before almost 20 days of bud opening with open tops for fresh air to pass and after about one month, the bottom side is also opened to allow free ventilation and to avoid fungal or bacterial growth. After another fortnight, the sheets are further loosed and completely removed one week later. By this strategy we can manage to increase day and night temperatures at 8 and 2 ^{0}C respectively, thus reducing the time of bud opening by 7-10 days. When compared with the uncovered plants, an extra 6-7 kg average weight of grape fruit was recorded from the covered plants and fruits become commercially available around 20 days before the control group and even the taste of the fruits from covered vines was better than the uncovered ones [117, 118].

Protection from Hail

Hail is a not so common natural precipitation but can be highly detrimental for vineyards by affecting the growth cycle of grapevines as well as the table quality of berries [119]. Extent of damage is related to the amount and size of hail and duration and time of hailing [120]. There are certain amino acids and other bio-stimulants which are used to recover the effects of hailing, up to a certain extent [121]. In another study hail nets were applied for covering plants during hail fall. The experiment was a success in terms of physical safety from not only hail, but also from birds, animals and certain pathogens but at the same time, plant's physical processes like transpiration and gaseous exchange were a little bit affected although no compromise in biochemical composition was observed [122].

A more technical approach is the use of Cloud Seeding, which is a form of weather modification using silver iodide. Man-made ice-forming nuclei disturb the hail formation process and reduce the size of hail stones. Although, according to other researchers, the said technology can cause disturbance in the natural phenomena leading to an unbalanced situation, which can in turn cause climate changing challenges [123].

Genotype Selection

Under adverse climatic conditions grapevines cannot produce the expected yield and sometimes cannot even survive so in order to make the plant more powerful and resistant against environmental extremes, different combinations are made by joining rootstocks and scions with required qualities [124].

Some of the rootstocks have excellent tolerance against climatic extremes due to their origination from such climatic regions. Those vines are not preferred to be used as commercial plants because of the poor quality of berries but when grafted with excellent commercial varieties, satisfactory results can be obtained. The wild penetrating roots of the grafted plant go deep into the ground and pull water and nutrients efficiently. Wild species are also responsible for vigorous productivity and growth. Wild types are also more tolerant against drought, salt or temperature stresses [125, 126].

Some rootstocks are resistant to drought and salinity in addition to being resistant against nematodes and fungus attack [127]. Some rootstocks have an effect on stomatal opening and thus can maintain the water status of vines [128]. They also alter the nutrient uptake of plant resulting in a shadow effect over the biochemical composition and taste of the berries [129].

Canopy Management

In order to mitigate the impact of climate change on vineyards, grapevines can be pruned and trained in specified manners [130]. Plants intake water from soil via roots and transpirational pull created by evaporation takes this water towards the leaves. From leaves water escapes into the open air but if the foliage volume is managed wisely, extra water loss can be avoided specially under the changing circumstances of weather. However, the frequency and intensity of pruning is critical so as plants are not over pruned but are controlled in size enough to maintain soil water and fertilizer status [131]. Once the berries start to ripen, it is advisable to remove some leaves in order to transfer soluble solid accumulation towards the fruits instead of the extra foliage and thus yield quantity is maintained without delay in harvesting time [132]. This theory about pruning was confirmed by others[133] for Sangiovese variety of grapes and also [134] for non-irrigated areas, depending solely on rainfall.

Fruit formation and ripening are also related to the time of pruning for instance if pruning is done just before the onset of spring, the vine will bear heavily which will exhaust the soil fertility and consequently will delay veraison [135]. In the early stages, it cannot be said with accuracy that either the vine is overloaded with crop or bearing normal fruits so fruiting buds should be thinned only if the climate is very dry [131, 136]. Furthermore, pruning and thinning cannot be considered as a wise choice all the time because in spite of reducing the water usage, they can sometime cause a reduction in crop volume also [25]. If leaves are removed proportionately above the grape bunches, water loss can be controlled without compromise on yield, in addition to controlling bunch rot but can expose the bunches for possible sunburn [32].

The main target of pruning operation is to avoid yield damage in any form along the whole fruiting period. Minimal pruning is suggested to delay ripening of fruits under severe hot weather. It also ensures the reduction in attack of bunch rot [137]. Leaf thinning helps in keeping the sugar content of fruits under control so that the taste and quality of juice is not affected by over-fruiting. In addition to this, the shape of the vine also influences the amount of light absorbed and fresh air passed through the canopy. High foliage density reduces sun scorching but at the same time can cause rotting of over shaded and suffocating parts of vines. On the other hand, partially dense vine canopies can be seriously affected by frost damages and unfavorable air flow. Hence a balanced ratio should be applied while training and pruning the vine canopy [138].

Under some cases, high density plantations can be recommended along with regular pruning because in this way vine size is easily adjustable but the roots have to face competition with others and thus they grow deeper for water and nutrient intake, consequently strengthening the vine [54]. Goblet and Guyot systems of training keep the plant stature short and thus provide a smaller area for water loss as evapotranspiration from stem. In this way, water sources can be used precisely in arid areas [32]. In areas where extremely low temperature prevails round the year, grapevines can be trained to be short statured so that the bunches hang close to the soil level, which is normally warmer than the air above them. Also, if the orchard floor is made of gravel, then the temperature will be even higher to protect bunches from cold weather. On the other hand, if air temperature is higher than the desired range then training is done to provide partial shade to the delicate parts [35]. A 1 m2 foliage area is enough to support 1 kg of fruit bunches on vine. If this ratio is not balanced then either quality or quantity of the produce is affected [139]. If grapevines are pruned in late winter, buds will open later and if further delay is required, pruning is done after 2 or 3 leaves have sprouted in spring. This practice eliminates the bad weather effects without effecting the yield and quality [140]. In fact the sensory and organoleptic acceptance of wine extracted from such vines was higher [141]. Fruit ripening and maturity can further be prolonged by pruning the vines after sprouting of buds [135, 142].

Grapevines trained by Goblet system require relatively less water and can stand drought conditions like less than 350 mm of rainfall annually. The only concern about adapting this system is the difficulty in harvest of fruits by machines due to complex struc-

ture and if bunches can be harvested manually then this system can be successful [143].

Vineyard Floor Management

Not only the number of vines per unit area, but the planting system in the vineyard is also effective in defining the extent of damage caused by climatic extremes. Along with these, extent of soil tillage, soil depth and amendments added in the soil are also important in combating with the changes in climate. As we cannot resist the changes in climate, we have to manage our production techniques and apply some genetic modification techniques in order to get maximum production from vineyards [25]. Soil porosity, structure and proportion of several components in a soil sample define the rate of water infiltration and water loss from the ground as run-off. In order to enhance the water holding capacity of soil certain amendments like biochar etc. can be used which not only improve the soil structure and water content but also make the soil fertile. In addition to that organic matter also alter the soil fauna which buffer the effects of both long term and short-term changes in climate [144].

If the soils are tilled when water is available, it can be retained for longer duration [145]. But in order to conserve moisture and nutrients in the soil heavy tillage is not recommended. Furthermore, it damages the lifecycle of many beneficial microbes in soil in addition to increasing the rate of decomposition of organic matter in soil. If the vineyard is on steep area than soil erosion can be more threatening specially if the vineyard floor is bare and not covered with some mulching material. If the ground is covered by green compost, it can serve the double purpose of mulch as well as rich source of nitrogen and carbon. Compost also conditions the soil but addition of unnecessary compost, without prior sampling and examination of soil can lead to nitrate toxicity in underground water along with over growth of plants causing dense foliage which leads to rotting and less reproductive growth [146, 147].

Planting geometry and population of vines per unit area of orchard is an important concern. By increasing the distance between plants or rows, water consumption can be reduced. Alternatively, if grapevines are densely planted, they will be shaded from intense heat. Hence a compromise is to be made between plant number, input costs and expected outcome from the vineyard and some models have been suggested for that according to the prevailing climatic conditions of locality [59]. Further, if the soil is deeply ripped, roots will penetrate deeper and vine strength will increase. There are some algal or herbal inoculants, rhizobium bacteria and PGRs like protein hydrolysates, fulvic acid and humic acid etc. which when applied can increase the resistance in plants against external stresses along with providing nutrition to the vines and increasing the strength of roots [148].

Mulching

Mulching of the soil with different materials including the cover crops can be helpful in avoiding damage to the roots and to conserve moisture in hot weather, while preventing the soil water content from freezing in cold weather [149]. Covering the vineyard soil with polyethylene sheet can reduce the water requirement by half without any compromise over plant health [100]. The main purpose of using mulch is to cut the extra loss of water through high evaporation rate due to high temperature [150]. Both organic and inorganic mulches entrap the moisture inside enhancing the humidity [151]. In addition to this, organic matter also releases some water during decomposition thus conditioning the soil [152].

In vineyards, having a cover crop as an alternative for mulch is also useful as it forces the vines to penetrate their roots deep into the soil due to the competition on the surface, thus strengthening the plant [153]. Beside water conservation, mulching also helps in making the soil fragile and soft thus keeping the temperature optimum for roots and according to an estimate mulching can cause a reduction of around 25% loss in yield due to climatic changes [154]. Either polyethylene sheet or an organic mulch, both can hold water near the feeder roots of grapevines and at the same time can help the rootstock to grow quickly by conserving nutrients and necessary warm for the root growth, however, organic mulching is a better choice because of its zero harm to environment [155].

A few examples of mulching materials are polypyrene, polyester, polyethylene, wood shavings, wheat or rice straw, fallen leaves

and cow dung etc. [154]. Mulches check the attack of some harmful insects while also conserving the temperature of soil in optimum range, hence, are highly appreciated for application in both dry and extremely frosty climate. Due to their short life-span they serve as green manure each year in soil. They also do nitrification depending upon the type of cover crop but if their population is much higher than required, they will compete with vines for limited resources and can lead to an overall scarcity of resources [156].

Controlled Irrigation

Irrigation water quality, quantity and frequency of irrigation have a pronounced effect on vineyard health and productivity. In addition to that, the method of irrigation is of prime importance [157]. While deciding irrigation schedule, rainfall deficit needs to be calculated and the exact amount of water needed is provided through a suitable irrigation system, especially in early and late stages of production [158]. Sprinkler, under-crown sprinkler, subsurface, gravity, high-pressure, partial root-zone drying, micro and drip irrigation systems are more helpful in maintaining the needs of vineyards under unfavorable climatic conditions [9, 159, 160]. In the current scenario of constantly changing climate of world, in some warm areas with only a little precipitation, around 60% increase in grape production can be witnessed if vineyard is irrigated with artificially controlled methods [161, 162].

In fact, for vineyards, artificial irrigation has benefits over natural rainfall because the later cause berry cracks, fungal infection, insect attack, delay in hardening of vine wood and loss of fruit flavor. Likewise, we can check the water supply almost a month before harvesting in the former case [9]. There are certain scientific tools that can be helpful in finding the moisture content in grapevine and according to that smart irrigation can be scheduled without causing loss of water or drying of plants [163]. However, if the plant physiology is already weak, irrigation alone cannot compensate for the yield loss [25] but situation can be controlled by applying deficit irrigation to the drought resistant rootstocks [31, 164]. Deficit irrigation is also helpful in improving the quality of wines both red and white but up to a certain limit [35].

There is a need to combine some short-term solutions with long-term policies in order to get the best out of a vineyard in the changing climate scenario because under certain harsh conditions of climate, irrigation cannot compensate for the yield reduction instead, it can even add to the management expenses of vineyards which is totally uneconomical [165, 166]. Moreover, due to the artificial water application, top soils are converting into saline soils. The process gets speed up almost 4 times when water evaporates fast due to increased temperature [167]. The possible solution to these problems is application of sweet clean water to the vineyards and to plant drought resistant varieties [168]. A more advanced approach is the use of closed-loop system that can be controlled as and when required by adjusting time and keeping a record of all the data [169]. Total evapotranspiration is measured and then amount of irrigation water is decided according to the current water status of the vine and water available in the soil [170, 171]. There are some modern techniques to estimate the inner water status of plant for finding the correct time and amount of irrigation like sap flow, dendrometer and acoustic sensor [172-174]. Mobile phone apps can also track the hydro-status of vines and set the alarm in case of emergencies [175].

Diseases and Pest Management

When grown under any kind of stress either environmental or internal, plant defense system weakens causing the plant to be more prune to diseases and insect-pest attack. Under these negative conditions, plants need protection against possible stress as well as against the targeting organisms. The protection can be either in the form of chemical control or organic control. For example, when grapevines are attacked by powdery mildew, despite of the fact that organic control can cause the grape bunches to lose 7% weight, while on the other hand chemical control can increase the grape bunch weight up to almost 14%, as the chemical composition of the treated fruits is affected by the application of any external agent, thus organic treatment is overall a better choice as compared to chemical sprays [176].

Chemicals containing copper and sulfur atoms were used frequently in past but now the trend has shifted more towards biological

agents and organic compounds [177]. Under certain circumstances, climate change can be counted as a blessing in disguise because some diseases and pests naturally reduce in number when exposed to different weather conditions. Thus, it's advisable to reduce the consumption of expensive and toxic chemicals against small population of pathogens. A comprehensive study of relationship of vineyard with possible pests and their control by natural elements is required [178]. There are some pests which were not so dangerous under normal situations but after climatic changes have emerged as serious threat to grape cultivation like mildews, rust, mealybugs, thrips, borers and mites etc. Weather forecast is helpful in estimating the possible threat level of pests and doing some preventive measures in advance. With the invention of mobile applications and provision of internet connection everywhere it is much easier to get weather forecast [179]. A lot of chemical sprays are applied on crops for eliminating pests and disease attack but their after effects on health and environment are detrimental so some algorithms have been suggested which can predict their possible attack so that preventive measures can be applied even before attack. In this way, chemical use can be reduced by 50% successfully [180].

Nutrient Management

Fertilizer application has a pronounced role in production and yield of vineyards, both under normal as well as changing conditions of climate [181-183]. Balanced nitrogen application is specifically helpful in altering the amount of nitrous oxide and methane released [184]. If proper irrigation and nutrition is supplied to the vineyard, soil structure and microbial content can be improved [185, 186]. Justified application of fertilizers is helpful in restoring the exhausted soils which have lost their organic matter due to high heat and temperature of surroundings [187]. It has been proved that by applying moderate fertilizer dose, not only the quality of grapes can be alleviated but at the same time global warming can be controlled because some fertilizers are responsible for producing greenhouse gases and global warming [188].

In some areas, growers do not prefer to use organic matter due to the risk of quality degradation of the produce but organic matter is necessary for successful production of grapes [189]. Organic manures can also provide sufficient nitrogen for successful vineyard growth. According to a survey more than 8.5% of vineyards were fertilized by organic manure in 2018 but in order to practice solely organic farming of grapevines, certain regulations of that particular area must be followed [190].

Wind Machines

Most of the grape growing areas face speedy, chilling winds during spring and fall which can cause chilling injuries to the vines. In such areas wind machines or huge fans are installed in the vineyard to mix the cold heavy air near grape vines with warm light air above them thus reducing the freezing injuries to plants. Consequently, the leaves and buds remain safe from frost bites due to extreme cold temperature during nights and hot days. For successful viticulture in such areas, installation of wind fans, their distance from each other, height as compared to plants and air shuffling power are vital aspects. Furthermore, the time of operation is also needed to be considered seriously in order to control unnecessary use of fuel and noise pollution generated by their operation [191].

A "Spatial Mesh Temperature Monitoring System" is hired for estimating the setting, area, haste of cold air pool and air mixing efficiency of machine. According to the measurements made in such areas, at night, during cool autumn and spring seasons, temperature can fall from 6 ^{0}C to freezing point within 2 hours, creating a freezing zone in vineyard but if the wind fans are installed properly with precise calculations, this cooling pool can be diminished in less than an hour. Now another benefit of having exact calculations is the saving of fuel because the machines are not operating uselessly. In order to get exact rate of air inversion in the microclimate, the labor should be aware of the existing and required temperatures so that he can manage the speed and power of wind machines accordingly. Another technical aspect is calculating the exact location of wind machines. If the land is even and plain, it is not a big deal but when the orchard is in the form of terrace, the microclimate of the terraces after each 1m distance is needed to be studied for being highly precise about prevailing conditions. With the help of drones and Environmental Visualization System, these calculations can be performed accurately without spending a lot of budget on them. EVS displays the 3-D model of the

orchard in terms of prevailing cool air pool and strength of the wind [116].

Miscellaneous Canopy Protectant Uses

To avoid harsh sun burns and scorching, Bordeaux paste and other solutions can be applied over vine's stem and sometimes even on the leaves [192]. There are certain materials available in market either as film forming polymeric solutions or as binders to block stomatal openings, which are applied over leaves to reduce the rate of transpiration by controlling stomatal movements under extreme hot and water deficient conditions. These films indirectly conserve solids but can cause an increase of plant temperature due to reduction in vaporization [193]. CaCO3, K2SiO3 and Al2Si2O5(OH)4 act as barrier to the sunrays and save the plant from dehydration [194, 195]. Al2Si2O5(OH)4 has been proved by many researches as an excellent savior of grapevine leaves from extreme climatic conditions. It also accelerates food making process and control unnecessary water removal during opening of stomata for gaseous exchange. Kaolin also improves the biochemical properties of the fruits like antioxidant content, hormonal balance, sensory and organoleptic properties [196-198], along with having positive impact on certain gene expressions [199].

Some scientists have also employed the use of living organisms [200] or their products like microbial treatments and plant extracts for enhancing the productivity of vineyards while keeping their quality up to the mark under stressed conditions [176]. The higher the temperature goes, more the evaporation from soil occurs which causes water table to decline in depth leaving the salts near the root zone. This salinity stress causes biochemical and physiological unbalance in grapevines. To neutralize this unbalance salicylic acid combined with chitosan have been used successfully [201]. In another study cerium oxide proved to be a good solution against salt stress when applied in terms of nanoparticles [202]. A single strategy can never be good enough so multiple strategies are adapted and applied side by side for better results [35]. There are some bio-stimulants, such as chitosan, seaweeds, humic acid and other herbal extracts which increase the resistance in vines against all kinds of stresses [203, 204].

Harvesting Techniques

With the mega shift in climatic conditions specially in terms of temperature and water deficit, fruit ripening and senescence periods have been disturbed [205]. Under extreme circumstances when climatic factors cannot be altered or controlled, the success of vineyard is solely dependent on harvesting method and post-harvest operations. If harvesting is done by mechanical harvesters, it can be quick but the problem is all the harvested fruits may not be uniform in terms of maturity but if harvesting is done by labor, then more than one harvest can be made possible and also fruits can be sorted on basis of their maturity easily [206].

The harvesting index of a fruit crop is closely related with the water available, prevailing climate conditions and light intensity. For fresh consumption, grape bunches are harvested at around 13-18 ^{0}Brix TSS but it also depends upon variety and commercial quality class [207, 208]. An important point to be kept in mind is the estimation of possible yield before harvest so that the necessary arrangements for harvesting operations, transport of produce, storage and marketing could be arranged beforehand. Crop Advisor or other related software applications can be used for future estimation of yield depending upon the present situation of vineyards. Certain chemicals like phytohormones, osmo-protectants and melatonin sprayed before the bunches are harvested can cause a bonus in antioxidant and polyphenolic content of grapes [209]. If auxins, humic acid or polyamines are sprayed then ripening can be delayed and further improvement in biochemical composition can be achieved with cultural operations [210]. For long travelling and to maintain the quality of grapes, bunches should be harvested after sunset when the climate is already cold and field heat removal is much easier [211].

Postharvest Management

There are some post harvested techniques suggested to counteract the effect of extreme adverse climatic conditions and maintaining the quality of harvested grapes [25]. Postharvest analysis for biochemical composition of grapes collected from different climatic zones can be a helpful tool for comparing the results and making strategies to secure the nutritional content as much as possible

from harsh environmental conditions [212]. Generally speaking, reduced temperature exposure is a good help for enhancing the postharvest life of produce [213]. When the produce is kept in the form of a heap, the internal fruits are highly prone to the attack of insects and enzymatic browning because of low oxygen and high humidity [214]. If the commodity is packed, the insect attack can be more serious because they find perfect environment there for their respiration and breeding. Cold storage at proper time and for proper duration is necessary because otherwise insects get more time for multiplication in the fruit lots. Field heat removal from fruits before transport and storage is helpful in reducing the incidence of pest attack [213].

If better transport facilities are available then storage houses should be shifted to areas with such a natural climate which is not suitable for highly damaging insects and diseases [215, 216]. After transportation, if there is still threat of disease attack, then the fruits should be quarantined for some time depending upon the lifecycle of suspected pest [217]. For detailed system development, a good dialogue and mutual cooperation between stakeholders, industrialists, growers, researchers and infrastructure managers is demanded [218]. There are also some industrial adaptations, especially in vine making, to compensate for the problems associated with grapes developed under adverse climatic conditions. For instance, application of certain yeast types combined with some membrane-technique in order to conserve acid content while decreasing alcoholic content [219].

Conclusion In protected viticulture multiple techniques are applied to save grapevines from extreme climatic conditions. Due to the continuous rise in temperature and reduction of water availability not only the plants are becoming weak but the pest attack has also become heavier and more frequent. Climate is a complex of several factors hence, it is almost impossible to control it, thus advance viticulture management is the need of the hour. A single strategy can never be enough to cope with the demands of climatic change thus a more innovative and integrated strategy should be adapted to reduce the detrimental effects of adverse climatic conditions.

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