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Factors affecting production of quality grapes (*Vitis vinifera*) for domestic and export market: a review

R G Somkuwar and Rutuja Nale

ICAR- National Research Centre for Grapes, P.B. No. 3, P.O. Manjari Farm, Solapur Road, Pune, Maharashtra, India

Abstract

Grape (*Vitis vinifera* L.) cultivars and hybrids of *V. vinifera* with *V. labrusca* L. and *V. amurensis* Rupr.) belonging to Vitaceae family of deciduous woody perennials are most widely consumed non-climacteric fruits globally. In India, table grapes are gaining popularity due to its various attributes and availability of nutritional compounds. The grape quality refers to various attributes, including appearance, colour, texture, flavour, and aroma. The ripening process begins at the veraison stage, marked by sugar accumulation, berry softening, anthocyanin production, metabolism of organic acids, and build-up of flavour compounds. The present review explores a wide range of factors that influence grape quality. The impact of cultural operations such as leaf removal, cluster thinning, shoot pinching, use of plant growth regulators and training system are of vital importance. The effect of temperature, light, water availability and rootstocks on grape quality are summarized.

Key words: Table Grape, Cultural practices, Fruit quality, Canopy Management, Vitis vinifera.

In recent years, especially in advanced economies, there has been a shift in food consumption trends as people have become more selective about their diets, showing an increased interest in health-oriented products. This health trend extends beyond just dietary needs and specific health conditions, encompassing various aspects of overall lifestyle (Nielsen, 2016). At the same time, consumers' healthy lifestyles are influenced not only by their health awareness but also environmental concerns. This shift in consumption is reflected in the increasing popularity of functional foods, organic products, foods produced with low environmental impact technologies, and biodegradable packaging (Markosyan *et al.,* 2009). To differentiate their products, agro-food companies have invested in health and environmental attributes, as consumers are willing to pay a premium for these features. Several food products that meet these criteria have been certified for their superior quality. In the fruit and vegetable sector, table grapes are a prime example of a food product with significant market potential in the functional food category. Grapes offer considerable health benefits due to their rich content of vitamins, minerals, lipids, fiber and is suitable for consumption by healthy people, given the large quantities of simple carbohydrates and calories (Skinner and Hunter, 2013). The beneficial effects of consuming table grapes are widely recognized.

Table grapes are abundant in bioactive compounds, but their concentration can be influenced by various factors, including grape variety, ripeness, post-harvest storage conditions, environmental aspects such as location, light exposure, temperature, nutrition, water availability, microorganisms, and viticultural practices (Chen *et al.,* 2020, Colombo *et al.,* 2020, Perestrelo *et al.,* 2012, Yang *et al.,* 2020). Colored grapes are particularly potent due to their high levels of phenolic compounds, which offer various biological effects and potential health benefits (Carrieri *et al.,* 2013). The quality of table grapes encompasses both intrinsic (such as visual, mechanical, and chemical characteristics) and extrinsic factors (including price, country of origin, cultivar, and production method). The consumer's perception of intrinsic attributes is often referred to as 'acceptability.' Consequently, perceptions of quality can vary along the marketing chain and among different consumer groups across various countries. Thus, sensory evaluation is an effective method for assessing consumer preferences and satisfaction.

Appearance plays a crucial role in how consumers assess the quality of table grapes, with visual factors like berry size, shape, and color being significant (Ferrara *et al.,* 2017). Additionally, taste, aroma, and texture are important, as consumers tend to prefer large, seedless grapes with a delightful flavor and aroma (Costenaro da Silva *et al.,* 2010). Seedlessness is a critical quality factor (Vargas *et al.,* 2013), as younger consumers favor seedless varieties because they are easier to chew, eliminating the astringency of seeds. Colour, ranging from pale green to nearly black, is a direct sensory attribute that affects the attractiveness of table grapes. Along with visual traits, physicochemical properties also play a role in assessing quality (Jayasena and Cameron, 2008). The texture of a table grape berry encompasses various attributes,

***Corresponding author :** rutujanale2502@gmail.com

including hardness, elasticity, shape, and the sensory experience during chewing. The sensory quality of table grapes is primarily influenced by total soluble solids (TSS), titratable acidity (TA), the composition of organic acids, and the balance among these factors. Total soluble solids, which correlate with ripeness, are a key grape property that aligns closely with consumer perceptions of berry quality and preference. While the balance of organic acids contributes to the overall mouthfeel and quality of table grapes, excessive acidity can reduce their palatability. Table grapes are harvested once the berries meet the minimum maturity criteria.

The aroma experienced while chewing grape berries is a crucial quality factor, which is mainly due to the unique volatile compounds present in each cultivar. Muscat aroma is highly valued in grapes intended for fresh consumption and is closely associated with monoterpenes like linalool, rose oxide, citral, geraniol, nerol, and citronellol. The quality of table grapes often declines, whether they are still on the vine or during storage, presenting a significant challenge for stakeholders. A major postharvest issue for table grapes is their vulnerability to grey mold, which can shorten their shelf life during storage and retail display.

Cultural practices

Under tropical condition, grapevine is pruned twice in a year (once after the harvesting of fruits called back pruning and after the cane maturity during October is called forward pruning). The cultural practices followed during each pruning are different as they are based on the objectives like achieving effective fruit bud differentiation and development of a grape bunch. Though the fruit bud differentiation is totally dependent on the practices followed during foundation pruning, production of quality grape depends on cultural practices followed after fruit pruning. The practices consist of pruning position, cluster thinning, crop load management, retention of berries in a bunch, girdling, thinning, etc.

Cluster thinning

Thinning is a standard viticulture practice used to manage yield levels to enhance the quality of harvested grapes and prevent over cropping, especially in regions with production yield restrictions. Cluster thinning involves removing a percentage of the developing grape clusters, typically between 30 and 40%, to promote better vine balance (Carmona-Jimenez *et al.,* 2021). Cluster thinning affects yield reduction, accelerates grape maturity, and enhances the phenolic content mostly in wine grapes. Several studies (Hannam *et al.,* 2015; Preszler *et al.,* 2013) have indicated that the "marginal profit" -the quality improvement that compensates for yield loss -resulting from cluster thinning is significantly diminished, while likelihood of negative side effects (such as increased growth from the remaining clusters, which may become more compact and produce larger berries with a lower skin-to-pulp ratio) is heightened. On the other hand, cluster thinning can be crucial in situations of over cropping, where there is a clear need to achieve or accelerate ripening, particularly in cooler climates (Zhuang *et al.,* 2014). In these studies, total soluble solids (TSS) and colour significantly increased in thinned vines, while titratable acidity (TA) decreased and pH increases. Cluster thinning is a common practice in managing table grape vineyards to enhance fruit quality (Somkuwar *et al.,* 2018). In Jumbo Seedless (Nana Purple), cluster thinning done after berry set showed positive effects on quality, with higher berry and cluster weight (Somkuwar *et al.,* 2014).

Shoot pruning

Shoot pruning is a widely used mechanical practice that helps to maintain the shape of the canopy, controls vine growth, control the incidence of diseases, and ease access for harvesting and machinery in vineyard rows. The impact of shoot pruning on grape quality is closely linked to the number of leaves left on the stem after cutting, as well as the quantity and effectiveness of lateral shoots stimulated by the pruning process which, in turn, are a function of timing and severity. VSP trellises are typically trimmed when the shoots surpass the top wires, so the timing is largely determined by the natural vigor of the shoots and the balance of the vine, rather than by the grower's choices. In a balanced vineyard, trimming would occur around fruit set, while a highly vigorous vineyard would reach that growth stage much earlier, potentially requiring additional trimming later in the season. The timing for trimming changes for sprawling canopies (such as a single high wire trellis), where pre-flowering trimming may be needed to encourage more upright shoot growth (Poni *et al.,* 2014). In various red and white grapevine cultivars grown on fertile soil and trained to a single high wire trellis, hedging at the 9th to 10th node on primary shoots one week after bloom resulted in higher levels of total soluble solids (TSS), phenols, and anthocyanins in the red cultivars, while also lowering the titratable acidity (TA) and juice pH across all cultivars (Cartechini *et al.,* 2000). Bondada *et al.* (2016) demonstrated that post-veraison shoot trimming can effectively reduce cluster compactness in Sangiovese without negatively impacting overall fruit quality. Under the tropical condition, table grape variety Thompson Seedless and its clones are imparting more vigor. Considering the production of quality grapes, maintaining source: sink balance is important after fruit pruning. The vegetative growth on a fruiting shoot will be up to flowering and will cease after the berry setting. Hence, the balance needs to be maintained by retaining 10-12 leaves (160-170 cm^2) above the grape bunch and pinching the remaining leaves.

Leaf removal

Basal defoliation, which involves removing leaves in the cluster zone, is a common canopy management practice used to modify the microclimates in the fruit zone. The effects of the timing and intensity of this practice vary with the use of variety and climate available in that area. Basal leaf removal effectively reduces foliage cover in dense canopies, improving light exposure for the clusters, increasing canopy porosity, and helping to control the incidence of bunch rot disease (Mosetti *et al.,* 2016; Wang *et al.,* 2018). Canopy management techniques such as shoot trimming, cluster thinning, and leaf removal alter fruit-zone microclimates and influence grape and wine quality by affecting the composition of primary and secondary metabolites. Additionally, clusters exposed to sunlight due to leaf removal typically show higher levels of soluble solids, anthocyanins, and flavonols, while having lower levels of malic acid and titratable acidity compared to control vines (Diago *et al.,* 2012; Sternad *et al.,* 2013). Basal defoliation is particularly prevalent in cool climate viticulture, where solar heat accumulation is low and humidity and rainfall are high (Frioni *et al.,* 2017). However, under tropical condition, the removal of excess leaf may lead to sunscald on the grape berries, early ripening of grape bunch, etc.

The timing and intensity of leaf removal significantly impact berry composition: late defoliation at veraison can lead to increased sunburn incidence, negatively affecting anthocyanin biosynthesis even under temperate condition. In contrast, early defoliation before blooming can positively influence berry composition by changing the source-to-sink ratio, reducing cluster compactness, and preventing solar overexposure of the clusters. Under high temperature and low humidity conditions after veraision stage of grape bunch, the leaf removal below and above the grape bunch does not require as it may lead to change of green colour to amber green. The leaf removal before berry setting may help to control the development of microclimate thereby supporting the effective spray coverage and disease control. Somkuwar *et al.* (2024) revealed that retaining 10-12 leaves above the bunch in Nanasaheb Purple Seedless grape variety provide maximum bunch weight, berry size, yield/vine and total soluble solids.

Shoot thinning

The aim of this management practice is to ensure optimal canopy density and/or crop level, typically carried out at 4-5 leaf stage, which is approximately about 16-17 days after fruit pruning. An enhanced canopy microclimate and improved physiology can be achieved with a shoot density of 15–25 shoots per meter of vine (Somkuwar *et al.,* 2014). Mainly, shoot thinning reduces vine yield and titratable acidity, whereas improves TSS, anthocyanins and aromatic compounds (Bernizzoni *et al.,* 2011). In Tas-A-Ganesh, Somkuwar *et al.* (2014) have shown that when shoot thinning reduced shoot density from 40 shoot per vine with or without leaf removal followed by shoot pinching had significant impact on photosynthesis and transpiration rates.

Cane girdling and application of plant growth regulators

Girdling (removing ring of bark) the trunk or cane is traditional horticultural practice can be done immediately after fruit set to improve berry size, sugar content, and again at the onset of fruit ripening or softening to boost color and to promote early berry maturation (Pereira *et al.,* 2020). The disruption of phloem vessels is temporary, lasting a few days, after which the vine repairs them by producing a callus. This technique is more commonly applied to seedless table grape varieties to enhance their size (Tyagi *et al.,* 2020). Gibberellic acid (GA3) has been used extensively to control berry size, berry set and weight, to decrease cluster compactness and to induce seedlessness in grapes (Ramteke *et al.,* 2010).

Application of GA3 at different concentrations to seedless table grape cultivars is a common practice for elongating the bunch, thinning flowers, and increasing berry size. Depending on the purpose, GA3 can be applied at different growth stages: 1) pre-flowering, to elongate the rachis length and panicle growth; 2) during flowering, for thinning flowers of seedless grapes; 3) post-flowering and fruit-set, to increase the berry size and production of loose bunch (Somkuwar *et al.,* 2019)). In recent year, there has been a significant use of plant growth regulators to increase berry size and yield. Cytokinins, commonly combined with gibberellins, are especially effective for enhancing berry growth by stimulating cell division and elongation.

The most widely used cytokinin in viticulture is forchlorfenuron, marketed under the trade name CPPU (Ramteke *et al.,* 2006; Yu *et al.,* 2021; Rojas *et al.,* 2021). Exogenous application of ABA is used in table grape production to accelerate ripening and enhance the color of various grape varieties (Lurie *et al.,* 2009;

Ferrara *et al.,* 2015: Koyama *et al.,* 2019). The effects of S-ABA on the color of Crimson Seedless grapes are due to changes in both the total anthocyanin concentration and the ratios of different anthocyanin types (Ferrara *et al.,* 2015). Additionally, the application of the ethylene-releasing compound 2-chloroethylphosphonic acid promoted anthocyanin accumulation and accelerated ripening. Other substances like methyl jasmonate, 1-aminocyclopropane-1-carboxylic acid (ACC), coronatine, and ethephon also triggered the abscission of mature grapes from raisin, table and wine varieties.

Training system

Implementing a suitable training system enhances the exposure of clusters and canopy to sunlight and air circulation, leading to improved berry quality. The choice of training system (such as bower, Y- trellis, expanded Y - trellis) can significantly influence various cultural practices, positively impacting the quality of table grapes (Somkuwar *et al.,* 2024). Training systems require varying leaf area to crop weight ratios to achieve the ideal levels of total soluble solids, berry weight, and berry colour at harvesting. Somkuwar *et al.,* (2019) revealed that vine trained on expanded Y training system with double cordon horizontal canopy modification performed better for growth and yield and reduced disease incidence. In some area of table grape cultivation, plastic covers are used as shade net to protect grape bunch from adverse climatic conditions or to accelerate the early ripening (Ramteke and Somkuwar, 2007).

Soil management and fertilization

Pre-veraison calcium applications had a significant impact on fruit mechanical characteristics, resulting in increased flesh firmness and berry breaking force, as well as reduced *B. cinerea* rot during storage, thereby preserving postharvest fruit quality (Ciccarese *et al.,* 2013; Yu *et al.,* 2021). Applying calcium in the early stages of fruit development also promotes an increase in final berry size. The recent use of cover crops in table grape vineyards has decreased vine vigor, leading to improved yield and berry quality (Muscas *et al.,* 2017).

Environmental factors

Temperature

Climate has a major impact on grapes, and extreme high-temperature events can affect grape berry development and, therefore, the quality of grape (Blancquaert *et al.,* 2019; Barnuud *et al.,* 2014; Somkuwar *et al.,* 2023). Some areas have good conditions for grapes production due to favorable climatic conditions that positively influence grape development. It is anticipated that the warmer and drier conditions expected in the future could negatively affect viticulture in Indian-climate regions. Mild climates favorable for grape production, and grapevines have adapted well to these conditions. However, shifting in grape production areas are occurring mainly due to climate change and the use of irrigation in vineyards. Selecting specific cultivars, training systems, soil cover, pruning methods, and mulch usage are crucial in grape production, as these factors are essential for extending grape cultivation to various areas and potentially overcoming environmental constraints. It has also been known that the climate influence grape quality. Warmer temperatures increase metabolic rates and impact the synthesis and accumulation of certain metabolites, including secondary ones such as polyphenols and flavonoids like anthocyanins (Blancquaert *et al.,* 2019). Elevated temperatures accelerate grape maturation, resulting in an increase in total soluble solids content. Additionally, phenolic compounds are also affected by temperature changes (Barnuud *et al.,* 2014). Climate change profoundly affects the phenylpropanoid pathway, which is crucial for polyphenol biosynthesis. These alterations can interfere with the synthesis and accumulation of these metabolites, as well as influence the activation of enzymes and genes involved in their production (Marchica *et al.,* 2020).

Enzymes responsible for anthocyanin biosynthesis function best at temperatures between 17°C and 26°C. However, temperatures above 35°C can lead to the degradation of anthocyanins and hinder their accumulation (Cevallos-Casals *et al.,* 2004). Numerous studies have demonstrated how varying climates affect the accumulation of anthocyanins and organic acids (Barros *et al.,* 2014; Torres *et al.,* 2016; Rodríguez Montealegre *et al.,* 2006; Boas *et al.,* 2014). Plants, including vines, are poikilothermic organisms, meaning they are influenced by temperature, which impacts the vine's phenology, vegetative cycles, and grape quality (Rouxinol *et al.,* 2023).

Light

Light influences the growth and composition of a wide variety of fruit, including grapes. Plant physiological processes, such as photosynthesis, chlorophyll production, transpiration, and carbon dioxide absorption, fluctuate with phenological stages and influence seasonal growth responses (Canton *et al.,* 2017). In the annual grapevine cycle, vegetative phenology plays a crucial role, as it relates to light capture and the conversion of that light into food reserves. Vines utilize carbohydrate reserves from the previous season to trigger bud burst and break dormancy, followed by the initiation of shoot growth and the commencement of photosynthesis (Campos *et al.,* 2016). An increase in reflected light may enhance the transport of photosynthetic products from leaves to grape berries, leading to greater sugar accumulation (Tian *et al.,* 2023). Additionally, light has been found to correlate with berry weight. Organic acids tend to be more sensitive to environmental conditions than other physicochemical parameters. Aroma is an important aspect of quality in grapes and can be regulated by the light intensity of the environment.

Water availability

Water availability is arguably the most important environmental factor limiting crop growth and productivity. The water requirement varies with different growth stages of vine. During the fruit pruning season, it is important to irrigate the vines promptly to encourage robust shoot growth and sufficient leaf area. In Indian vineyards, since fruit set is generally not an issue, applying mild stress from berry set to the shatter stage (berry dropping) can help manage berry set, reducing the need for thinning. The period from berry growth to veraison is critical, as cell division and elongation are taking place in the fruit. Water stress during this time can lead to smaller berries and lower yields. Hence, from veraison to harvest, care should be taken not to over-irrigate to prevent berry cracking and delays in harvesting. However, moisture stress during this phase can cause berry drop.

Rootstock

Rootstocks not only play a vital role in pest and disease management but also significantly contribute to improving grape quality by effectively addressing abiotic stresses, particularly drought and salinity tolerance (Somkuwar *et al.,* 2024). A wide variety of rootstocks are available for grape cultivation, each suited to different production challenges. Among the different rootstocks available, Dogridge rootstock has gained popularity among grape growers for its ability to withstand abiotic stresses and for its favorable stionic combinations. However, a rootstock that works well for one variety in a specific location may not be suitable for the same variety in a different area, leading to varied choices of rootstock across different cultivars (Somkuwar *et al.,* 2023). Rootstock significantly affects physical characteristics of grape bunches, such as size and compactness, as well as chemical properties like total soluble solids and acidity in the berries. While rootstock can influence titratable acidity in warmer climates, factors such as year and soil type may have a more substantial effect (Keller *et al.,* 2001). Vines grafted onto the 5C rootstock exhibited significantly lower sugar accumulation compared to other rootstocks, though sugar levels (Brix) at harvest were similar across all rootstocks; however, vines on 5C had reduced titratable acidity (Nuzzo and Matthews, 2006).

Somkuwar *et al.* (2013) noted that the quality and biochemical composition of cane varied with cane thickness in both own-rooted and grafted Tas-A-Ganesh grapes, observing that TSS in berries decreased as berry size increased. Additionally, berries from grafted vines had lower TSS compared to those from own-rooted vines, while reducing sugars, carbohydrates, and phenols were higher in grafted vines. Manjari Naveen grafted on Dogridge (*Vitis vinifera* L.) produced highest fruitfulness, TSS, yield and grape quality (Somkuwar *et al.,* 2024)

Technologies for assessing grape quality

Traditional monitoring of grape quality relies on measuring chemical and technological parameters, including total soluble solids, reducing sugars, pH, and titratable acidity, along with visual inspections. This information is primarily used to optimize the timing of the harvest. These methodologies are accurate and reliable, they are increasingly seen as limited due to their high costs, time requirements, destructiveness, and low environmental friendliness resulting from the chemical reagents involved. Recently, there has been significant interest in modern technologies that can address the limitations of traditional analytical methods while providing high robustness and precision in their results. Many of these new methods can be classified as non-destructive technologies, utilizing measurements that rely on the physical and chemical properties of sensors, such as light energy, irradiance, fluorescence, optics, and acoustics, and how they interact with plant tissues. Chemometry, a multivariate statistical approach, enables the integration of non-destructive data with destructive chemical attributes of grapes to create predictive models for assessing chemical parameters in intact and unfamiliar samples.

Non-destructive measurement sensors can be categorized based on their method of application into remote and proximal types. Remote sensors conduct measurements from a distance using aircraft, UAVs, or drones, while proximal sensors operate through direct contact, typically using ground vehicles like tractors or robots, or are operated manually with hand-held devices (Matese and Di Gennaro, 2015). Various workers have documented the use of NIR technology to assess compositional parameters and maturity indicators in homogenized grape samples, as well as in grape juices and musts. These parameters include total soluble solids, anthocyanins, ions, dry matter, condensed tannins, reducing sugars, electrical conductivity, pH, and volatile compounds.

Overall, the findings indicated that NIR spectroscopy is an effective technique for predicting reducing sugar content and TSS in homogenized grape samples and musts (Gonzalez-Caballero *et al.,* 2010). According to Dambergs *et al.* (2015), the determination of other parameters can be significantly influenced by how samples are presented and the low concentrations of the compounds being analyzed, such as volatiles and other secondary metabolites.

Advances in this field have enabled the spectral scanning of grape samples in various presentation modes, including intact grape berries and whole bunches, both in laboratories and in the field (Muganu *et al.,* 2013). Notably, a portable NIR-AOTF device, which utilizes acoustic-optical tunable filtering for spectral wavelength analysis, has shown promising results for monitoring the ripening process in intact grape berries. Regression models for analytical prediction were developed by linking spectral data with reference data from MIR spectroscopy (Barnaba *et al.,* 2014). Currently, the most commonly used laboratory equipment for analyzing grape musts is the WineScan from FOSS (Hillerød, Denmark), which employs MIR spectroscopy, Fourier transform (FT) techniques, and chemometric modeling (Patz *et al.,* 2004).

This device can accurately and robustly detect a wide range of grape parameters quickly and non-destructively. Giovenzana *et al.* (2013) successfully used a Vis/NIR device to predict ripening parameters such as TSS, titratable acidity, potential alcohol content, and extractable anthocyanins in both red and white grape samples directly in the field. NIR hyperspectral imaging is a technique that captures both spatial information and the spectral response for each pixel of the scanned object (Lorente *et al.,* 2012). It offers valuable insights into quality and maturity indicators in intact grapes and is especially well-suited for non-destructive applications in precision agriculture (Álvarez-Cid *et al.,* 2015). Recently, this method has been effectively used for the rapid and non-invasive assessment of anthocyanins, total soluble solids, pH, and sugar content (Fernandes *et al.,* 2015), as well as for evaluating grape aromatic ripening by integrating non-destructive detection with measurements of volatile compounds (Álvarez-Cid *et al.,* 2015).

All methods developed using vibrational spectroscopy technologies offer significant advantages, including non-destructive and rapid detection, reduced costs with repeated use, and environmental friendly analytical procedures. However, there are still limitations that may hinder their practical application, such as potential loss of spectral efficiency particularly in field settings and challenges in creating robust and reliable calibration models due to the extensive number of samples needed and the high biological variability of grape samples stemming from different varieties and origins.

These factors can also contribute to the relatively high costs of commercially available instruments. A technique known as chlorophyll fluorescence screening, which compares chlorophyll fluorescence emissions after excitation at two different wavelengths, has been tested and developed to indirectly measure grape phenolic content (Agati *et al.,* 2007; Cerovic *et al.,* 2008). A portable fluorescence sensor has been created and evaluated as an effective tool for determining phenolic content in various grapevine varieties in the vineyard (Ghozlen *et al.,* 2010). This device has also been manually used for mapping grape quality properties in the field (Baluja *et al.,* 2012) and for assessing anthocyanin content in grapes (Le Moigne *et al.,* 2010).

CONCLUSION

Recent advancements in grapevine genetics, biotechnology, physiology, and innovative cultural practices have provided a range of tools to achieve high quality, profitable yields, and controlled production costs. Quality is more readily attained by cultivating the right variety in the right place or region. However, the benefits of optimal terroir can be undermined by inadequate or poor cultural practices and canopy management. Key developments in grape quality management involve understanding the interactions between canopy microclimate and grape composition, as well as reinterpreting certain canopy management techniques to address specific challenges. With the wealth of knowledge available, applying the appropriate physiological principles and techniques tailored to each specific site can ensure quality grapes.

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