JOURNAL OF NATURAL SCIENCE AND LEARNING

p-ISSN 2963-1041, e-ISSN 2962-9837
Vol 3.No.2. 2024, pp. 1-14
Availble online
https://journalng.uwks.ac.id/index.php/jnsl

GROWING GRAPES IN A GREENHOUSE IS A NEW REVOLUTION

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ABSTRACT

Grapes (Vitis vinifera L.) is amongst the well-known fruits around the world. They are not only admire due to nutraceutical and extraordinary properties but also for the multiple uses, viz, wines, juices, raisins and fresh consumption, along with side uses as in medicines and molasses etc. The modern world is facing problems of climate change, water shortage, land limitations and multiple fold increase in population. In order to meet the needs of the ever-increasing human population, intensive cultivation with limited resources is vital. Greenhouse cultivation is one of the best options for production of delicate fruits like grapes, having specific environmental requirements for giving bumper commercial crop. Precision viticulture, adopted under greenhouse conditions helps in improving the quality and quantity of produce, without compromising environmental and economic aspects. Smart choice of rootstock, efficient irrigation method, justified pruning and training of vines, timely application of just the right amount of nutrients, proper management of growth media, temperature and humidity control according to the needs of the particular growth stages of plant and controlled pollination can make possible the availability of out of season crop. This system also provides opportunities for agrotourism and a more controlled environment for future research. Installment of greenhouse demands a lot of investment both in terms of money and expertise but once established, the returns are multiple fold compared to the early investment.

Keywords: *Grapes; viticulture; greenhouse; climate change; protected agriculture; precision viticulture.*

ABSTRAK

Anggur (Vitis vinifera L.) adalah salah satu buah yang terkenal di seluruh dunia. Mereka tidak hanya dikagumi karena khasiatnya yang luar biasa tetapi juga karena berbagai kegunaannya, yaitu anggur, jus, kismis, dan konsumsi segar, bersama dengan penggunaan sampingan seperti obat-obatan dan molase, dan lain-lain. Dunia modern menghadapi masalah perubahan iklim, kekurangan air, keterbatasan lahan, dan peningkatan populasi yang berlipat ganda. Untuk memenuhi kebutuhan populasi manusia yang terus meningkat, budidaya intensif dengan sumber daya yang terbatas menjadi sangat penting. Budidaya rumah kaca adalah salah satu pilihan terbaik untuk produksi buah-buahan yang lembut seperti anggur, yang memiliki persyaratan lingkungan yang spesifik untuk menghasilkan tanaman komersial yang baik. Pemeliharaan anggur yang presisi, yang diadopsi dalam kondisi rumah kaca membantu meningkatkan kualitas dan kuantitas produk, tanpa mengorbankan

p-ISSN 2963-1041, e-ISSN 2962-9837
Vol 3.No.2. 2024, pp. 1-14
Availble online
https://journalng.uwks.ac.id/index.php/jnsl

aspek lingkungan dan ekonomi. Pilihan batang bawah yang cerdas, metode irigasi yang efisien, pemangkasan dan pelatihan tanaman merambat yang tepat, aplikasi tepat waktu dengan jumlah nutrisi yang tepat, pengelolaan media pertumbuhan yang tepat, kontrol suhu dan kelembaban sesuai dengan kebutuhan tahap pertumbuhan tanaman tertentu, serta penyerbukan yang terkendali dapat memungkinkan tersedianya hasil panen di luar musim. Sistem ini juga memberikan kesempatan untuk agrowisata dan lingkungan yang lebih terkendali untuk penelitian di masa depan. Pembangunan rumah kaca membutuhkan investasi yang besar baik dari segi dana maupun keahlian, namun setelah rumah kaca ini berdiri, keuntungannya akan berlipat ganda dibandingkan dengan investasi awal.

Kata kunci: *Anggur; pemeliharaan anggur; rumah kaca; perubahan iklim; pertanian yang dilindungi; pemeliharaan anggur presisi*.

Artikel history:01-09-2024. Received in revised from:27-09-2024. Accepted:29-09-2024 Available online:29-09-2024. Ver: pre press

I. INTRODUCTION

The cultivation of grapes (Vitis vinifera L.) has undergone a significant transformation in recent years, primarily driven by the global challenges of climate change, water scarcity, and the increasing demand for high-quality produce. Grapes, known for their nutraceutical properties and multiple uses, including wine, juice, raisins, and fresh consumption, are facing unprecedented environmental pressures (Restani et al., 2021). Traditional viticulture methods, often reliant on favorable outdoor conditions, are increasingly unable to meet the rising needs of the global population. This situation has necessitated innovative agricultural practices, among which greenhouse cultivation has emerged as a groundbreaking solution (Droulia & Charalampopoulos, 2021).

Greenhouse viticulture offers a controlled environment that mitigates the risks posed by extreme weather conditions, such as frost, drought, and high temperatures, which can severely impact grape quality and yield (Droulia & Charalampopoulos, 2022). By precisely managing factors such as temperature, humidity, and irrigation, greenhouse systems allow for the consistent production of high-quality grapes, independent of external climatic fluctuations (Laurita et al., 2021). This method also supports sustainable intensification, ensuring that the increase in grape production does not come at the expense of environmental degradation (Badji et al., 2022).

The adoption of precision viticulture in greenhouses further enhances production efficiency by utilizing advanced technologies such as sensors, automated irrigation systems, and climate control tools (Li et al., 2023). These innovations not only improve crop yield and quality but also significantly reduce the environmental footprint of grape production by minimizing the use of chemical inputs and optimizing resource use (Pisciotta et al., 2022). Additionally, greenhouse cultivation allows for the possibility of out-of-season grape production, which is a lucrative option for growers seeking to maximize profitability (Shahbazi et al., 2023). While the initial investment required for greenhouse infrastructure can be substantial, the long-term economic benefits, such as reduced pesticide use, higher yields, and extended growing seasons, make it an attractive option for modern viticulture. This revolutionary approach to grape cultivation holds the potential to reshape the future of the grape industry, offering a sustainable and profitable solution to the challenges posed by climate change and global food security (Garcia-Navarro et al., 2023).

Problem Statement

In light of the growing environmental challenges and the increasing global demand for high-quality grapes, it becomes imperative to develop sustainable viticulture practices that can ensure consistent production. The key question this study seeks to address is: How does greenhouse cultivation affect the growth, yield, and quality of grapevines under controlled environmental conditions, and what are the best practices for optimizing these factors to achieve sustainable production?

This research aims to explore the effects of different greenhouse management techniques on grapevine performance, with a focus on understanding how controlled irrigation, temperature regulation, and nutrient management can improve yield and fruit quality. By addressing these issues, this study hopes to contribute valuable insights into the potential for greenhouse viticulture as a viable solution for overcoming the limitations of traditional open-field grape production.

II. METHODS

This study employs a quantitative approach to investigate the effects of greenhouse cultivation on grapevine yield and quality under controlled environmental conditions. The methodology was structured in the following steps:

2.1 Greenhouse Setup and Environmental Control

A commercial greenhouse was established to maintain optimal growing conditions for grapevines. The greenhouse was equipped with temperature, humidity, and light control systems to simulate conditions conducive to grapevine growth throughout different phenological stages (Li et al., 2023). Sensors were installed to monitor and adjust the microclimatic variables automatically to ensure precision viticulture (Pisciotta et al., 2022).

2.2 Selection of Plant Material and Germplasm

The grapevine cultivar 'Sugraone' was selected for this study due to its proven success in greenhouse conditions (Kontaxakis et al., 2023). Grape cuttings were propagated using a controlled environment to ensure uniform growth, following the protocols for rooting and initial growth stages as described by Kizildeniz et al. (2022). The cuttings were treated with ozone to prevent pathogen contamination before planting (Laurita et al., 2021).

2.3 Irrigation and Nutrient Management

The regulated deficit irrigation (RDI) method was applied to optimize water use efficiency without compromising grape quality. Water requirements were monitored using a wireless network of soil moisture sensors, and irrigation was adjusted accordingly (Pinillos et al., 2020). Nutrient application followed the recommendations of Chang et al. (2021), with a focus on enhancing the uptake of potassium, which is critical for berry development (Hu et al., 2023).

2.4 Experimental Design

p-ISSN 2963-1041, e-ISSN 2962-9837
Vol 3.No.2. 2024, pp. 1-14
Availble online
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The experimental design was a randomized complete block with three replications. Each replication consisted of 10 vines per treatment group. Treatments varied in terms of irrigation intensity and nutrient composition to evaluate their effects on grapevine performance under controlled conditions.

2.5 Data Collection and Analysis

Data on grape yield, berry size, and sugar content were collected at the harvest stage. The maturity of the berries was determined using near-infrared hyperspectral imaging, which has been proven to provide accurate assessments of fruit quality parameters (Gao et al., 2022). Statistical analysis was performed using ANOVA to compare the effects of different treatments on grapevine growth and productivity. Post-hoc tests were conducted to determine significant differences between treatments at a 95% confidence level.

III. RESULTS AND DISCUSSION

3.1 Grape Production: Importance and Problems

Grapes are grown on nearly 7.5 million hectares around the world. 75 M tons of grapes are already produced around the globe annually with 50-71% of this produce being used by wine industry, 27% used as table fruit and rest of 2% used as raisin (Restani et al., 2021). Grapevines are perennial plants so crop rotation and some of the other management practices are either impossible or limited in a vineyard and thus they face direct negative effects from adverse changes in temperature, humidity, water supply, soil management practices and light intensity etc. Grapevines are sensitive towards weather extremes like frost and scorching heat or winds (Droulia & Charalampopoulos, 2021). High temperature leads to early ripening even without physiological maturity of berries thus not only the taste and time of harvest are affected but also table life is reduced. This early ripening leads to a competition between vegetative and reproductive growth of vines, causing power veraison and reduction in nutrient accumulation in berries. Certain grape varieties have been tested successfully in tropical areas but the only concern is extreme high temperature during summers and insufficient chilling hours during winters. If water supply and temperature is maintained artificially commercial yield can be taken in such areas too (Sabir et al., 2018).

Precipitation time and volume also have critical importance in viticulture particularly in rainfed areas. Extra water in soil or growth media enhances vegetative growth so much that vines become lanky and reproductive growth is severely compromised, fruits become watery and ripen late thus reducing next year crop (Droulia & Charalampopoulos, 2022). Dry spells although essential for reproductive stages and for enhancing antioxidant content in the fruits, if persistent for long durations can reduce the production notably and if followed by heavy irrigation, can even kill the young vines (Cabral et al., 2022). Sunlight availability is essential for normal vine growth, meanwhile intensity and duration of exposure is important. The exact intensity and length of exposure cannot be predicted accurately due to the complex relation between light and heat. Increase in light intensity increases chances of photosynthesis but by indirectly increasing temperature, can cause sunburn (Droulia &

p-ISSN 2963-1041, e-ISSN 2962-9837
Vol 3.No.2. 2024, pp. 1-14
Availble online
https://journalng.uwks.ac.id/index.php/jnsl

Charalampopoulos, 2021). Same is the case with carbon dioxide, which is supposed to enhance vine growth and food production, but due to the heating side-effect, it can lead to irreversible damages. The grapevine is a delicate plant in terms of pathogenic attack and is host to a wide variety of diseases and insect-pests e.g. phylloxera (Daktulosphaira vitifoliae Fitch). Environmental stresses including drought, heat, salinity and land erosion can be serious threats for grape cultivation. Chemical sprays and fertilizers are also reducing the quality of land and water thus some safer alternatives are required for sustainable grape production (García-Navarro et al., 2023).

3.2 Greenhouse

In order to compensate for the continuously increasing demand of grapes by the consumers, the area under grape cultivation is supposed to be increasing 2% annually. However, increasing the viticultural area is impossible and more intensive cultivation is inevitable now. Intensive practices need to be efficient enough to not only satisfy the current needs of mankind but also be humble enough to not fetch the resources of future generations. To address this problem, the concept of "Sustainable Intensification" has been introduced which means enhancing production from limited land area, without causing damage to the environment, especially by releasing nitrogen and greenhouse gases. Precision viticulture can be more easily and economically adopted under greenhouse conditions as compared to open fields (Badji et al., 2022). Greenhouses are closed structures with translucent covers, which maintain the required microclimatic conditions for successful growth of a crop and work as independent units without being affected by external climatic conditions. 90% of the production from any crop is influenced by immediate climatic conditions (Pisciotta et al., 2022). Results can be further improved in terms of economics, if the greenhouse works by solar energy (Shahbazi et al., 2023). Greenhouses also reduce the need of frequent chemical sprays, which are needed by grapevines due to their susceptibility to fungal attacks, meanwhile giving 2 or 3 folds higher economic return compared to the open air vineyard (Yu et al., 2022). With change in the trend of wine consumption and demand for new different wines in market, vineyards were suggested to be shifted to more elevated areas, towards poles, with the result of disturbing the biodiversity and raising new economic challenges. The most logical suggested solution for the said situation is growing grapevines inside the greenhouses in almost any climatic region around the globe. However, for protected cultivation, economic aspects cannot be neglected both in terms of resources and outcomes (Ingle et al., 2022; Perria et al., 2022).

3.3 Aspects of Greenhouse Cultivation

3.3.1 Propagation

With the increase in the rate of climate change, vineyard failure is also becoming much more common. However, the demand for grapes in wine making and other industries is always increasing thus more healthy and qualitative vineyards are needed. For this purpose, grapevines multiplied by hardwood cuttings, grafting or tissue culture are appreciated. Rooting occurs faster at room temperature which is easier to achieve inside

p-ISSN 2963-1041, e-ISSN 2962-9837
Vol 3.No.2. 2024, pp. 1-14
Availble online
https://journalng.uwks.ac.id/index.php/jnsl

the greenhouse. Before planting cuttings are also treated with hot water or ozone for disinfection (Kizildeniz et al., 2022). However, when the aim of propagation is either getting varieties or breeding to produce new hybrids, controlled pollination under greenhouse conditions is easier to perform and thus required hybrid plants can be obtained by seeds (Svyantek et al., 2022).

3.3.2 Irrigation

When the water status of grapevine changes vine growth rate, fruit production capability and even microclimate around vines change. Leaf temperature is used as an indicator of water stress due to reduction in transpiration rate. Application of plasma activated water (PAW) is an innovative approach in greenhouse grape cultivation, for improving drought resistance in vines without compromising the taste and nutritional status of berries (Laurita et al., 2021). There are certain automated wireless networks for checking the plant water requirement and soil condition in terms of texture, moisture and micro-biodiversity. They use Bluetooth, GPS and other technologies to smartly handle time and quantity of irrigation for grapevines in greenhouses. Regulated deficit irrigation (RDI) is considered as a successful solution to drought problems. RDI improves the berry quality by applying just the right amount of water at the right time. RDI is also responsible for early crop production (Pinillos et al., 2020).

3.3.3 Temperature Control

Temperature is the key factor in success or failure of viticulture as every stage, from rooting till reproduction, is influenced directly or indirectly by temperature of surroundings. Covered greenhouse structures are excellent for maintaining high temperature inside and if panes are open air can be ventilated as and when required to maintain the optimum temperature according to the growth stage of grapevines. Regulating temperatures is crucial to prevent physiological stress from extreme temperatures, ensuring optimal yield and quality by synchronizing vegetative and reproductive growth. Utilizing sensors to track temperature offers a highly economical, intelligent and automated method to optimize effective temperature control in greenhouse grape production systems (Li et al., 2023).

3.3.4 Sunlight and Wind Control

Winds prevailing at the time of fruit bearing delay ripening and reduce berry size. Heatwaves during ripening adversely affect yield and berry quality. Excessive exposure of bunches to solar radiations can lead to sunburn and can also negatively alter the synthesis and accumulation of primary and secondary metabolites in the fruits (Garcia-Tejera et al., 2023). In order to assess the suitability of a region for greenhouse cultivation of grapes, the seasonal variation in total Photosynthetic Active Radiations (PAR) at canopy of vines is calculated. This variation is closely linked to total sunshine hours in a season (heliophany) and the light transmission properties of the covering material used in construction of greenhouse (Pisciotta et al., 2022).

3.3.5 Precision Viticulture

Precision Viticulture utilizes cutting-edge information technologies to enhance

p-ISSN 2963-1041, e-ISSN 2962-9837
Vol 3.No.2. 2024, pp. 1-14
Availble online
https://journalng.uwks.ac.id/index.php/jnsl

grape production by optimizing technical efficiency, maximizing quality, reducing environmental impact and mitigating risks of crop failure for growers and processors. It relies on advancements like global positioning systems, environmental sensors, remote sensing and geographic information systems to analyze and address variability in the vineyard. Through precision viticulture systems, factors such as soil fertility, fertilizer application, disease management, water usage, weed control, harvesting and environmental conditions can be monitored and managed effectively. Adapting and improving precision technologies in greenhouse viticulture is essential to minimize inputs such as fertilizers and pesticides while increasing yield and grape berry quality (Ozdemir et al., 2017).

3.3.6 Selection of Germplasm/Plant Material

The success of grape cultivation in greenhouse condition depends on the practical implementation of scientific knowledge e.g. development and planting of stress tolerant varieties which are also capable of growing under closed conditions. Prima (Sabir et al., 2019), Trakya İlkeren (Sabir et al., 2020), Allison, Black Magic, Centennial, Early Sweet, Matilde, Perlon, Regal seedless, Red Globe, Superior seedless, Sweet Celebration and Victoria are grown successfully in soilless media inside the greenhouse (Pisciotta et al., 2022). Chardonnay (Noyce et al., 2022), Sugraone and Prime (Kontaxakis et al., 2023) have also been tested successfully under controlled greenhouse conditions. Although grapevines are propagated by hardwood cuttings or grafting in greenhouses too but recent experiment utilizing green soft wood cuttings from fresh shoots of vines made year-round propagation of vines possible in greenhouses. Inducing bud sprouting in old vines artificially can also make out of season propagation possible (Noyce et al., 2022). However performance of rootstocks or cuttings can vary in greenhouses when compared to open vineyards (Martínez et al., 2023). For example by maintaining temperature and humidity, and using soilless sterilized media inside the greenhouse, rooting percentage can be enhanced without the threat of pathological attack from air or soil (Kizildeniz et al., 2022). Likewise, the growth and quality of seedlings grown for breeding purposes are critically important. Therefore, it is advantageous to cultivate those seedlings in greenhouses, where conditions can be controlled and kept clean, ensuring successful research trial (Svyantek et al., 2022).

3.3.7 Soil and Growth Media Management

For better growth of vines, soil amendments are added or a full soilless media is used in greenhouses. Organic amendments like biochar is considered better as they also provide nutrients thus reducing the burden of using chemical fertilizers (Chang et al., 2021). Improving the soil or growth media properties without casting any negative impact on environment is easier if it is supposed to be done in limited area (greenhouse), also closed structures do not impact the soils of nearby areas in contrast to the open vineyards (Cataldo et al., 2021). Soilless media can also alter the time of grape ripening (Pisciotta et al., 2022). Soilless cultivation of table grapes in zeolite and cocopeat media alone, as well as in 1:1 mixture gave excellent results under greenhouse. Soilless cultivation of grapevines relies on substrates ensuring proper moisture, supporting physiological processes and supplying nutrients. Perlite substrates show promising qualities for enhancing table grape production (Kontaxakis et al., 2023).

3.3.8 Container Planting

Container planting of grapevines with organic media under cont¬rol¬led conditions of greenhouse makes the rooting of cuttings much easier, leading to early production. A lot of nematodal and fungal diseases spreading through soil can be eliminated in container plantings and plant growth cycle can be manipulated easily in containers. Application of fertilizers, pesticides and other management practices can be easily carried out in containers. However, more intensive care is required as a small root volume has to support the whole vine. Growth media texture, structure, water and air holding capacity must be considered. In the modern practices, organic containers made up of salvaged paper, rise husk, bamboo, cow dung, wood shavings and coconut fiber are used (Gruda, 2019).

3.3.9 Covering Material

Covering materials with different thicknesses, transparency and lifespan are suggested, each with its own pros and cons. Selection depends on budget, external climatic conditions, ultimate aim and vine requirements. HDPE, LDPE, EVA, fiberglass and glass sheets are commonly used. If covering material is around 85% transparent to sunlight, early production, with better berry color and biochemical properties can be attained without using heaters. Colored sheets reduce the light intensity and result in better color retention in certain grape varieties. Under extreme warm conditions, over heating of the greenhouse can be avoided (up to 3 °C reduction) by opening side vents, using mechanicals ventilators or by evaporative cooling (Pisciotta et al., 2022).

3.3.10 Canopy Management

Proper structure and canopy volume of vines are to be maintained in order to avoid competition between vegetative and reproductive growth as well as to reduce the chances of fungal growth by allowing better light and air penetration. Spaces between plants, cordons and even berries on the same bunch are critically important. Canes higher from the ground (high cordon) improve vine health and berry quality. Double high cordon and double curtain trainings ensure better ventilation through vines (Dottori, 2023). Dormant pruning, removal of extra leaves according to pre-calculated leaf-to-berry ratio and cluster thinning must be performed timely to get commercial yield and maintain vine vigor. Under protected conditions, if on a 20-50 cm long branch 1 cluster is left, excellent quality grapes are obtained (Freeman et al.).

3.3.11 Insect-Pest Control

According to research 35% of all pesticides used in the world are consumed by viticulture. Under closed cultivation, Sauvignon Blanc rootstock provides resistance against certain insects, reducing the load on chemical sprays (Cooper et al., 2023). For flying insects, if poisoned baits, mixed with attractive lure, like yeast, are hung in the greenhouse, instead of spraying over fruits, residual toxicity can be minimized (Rehermann et al., 2022; Spitaler et al., 2022). If there is low temperature and rainfall at the time of harvest, infestation rate increases and greenhouse cultivation is advantageous for eliminating the environmental risks. Virus attacks are very common in viticulture. Some of the varieties can silence the viral RNA while other cannot, hence resistive varieties are chosen and multiplied in greenhouses (Čarija et al., 2022), also some gene markers are employed for checking the performance of vines under protected conditions of greenhouse (Ramos et al., 2022). Fungal attacks are a serious threat for greenhouse cultivation but certain bio-stimulants like chitosan have been found to reduce downy mildew attack by 30% (Mian et al., 2023). Not one single treatment can be suggested for all kinds of diseases and pest control thus the best management strategy is to combine them and apply as integrated approach (IPM) (Karampini, 2022).

3.3.12 Nutrition and Fertility

Grapes require particular nutrients at specific times in order to produce commercially accepted fruits owing to their delicate perennial habit. Berries need a luxurious supply of potassium for gaining optimal size and juice content. Complex fertilizers can indirectly affect the uptake of other nutrients, e.g. KNO3 improves nitrogen uptake (Hu et al., 2023). N improves growth, transpiration and photosynthetic rate under greenhouse conditions, however excessive use can damage reproductive health of vines. Se, Si, Ca, Mg, Cu and Fe supply is dependent on growth media as well as fertilizer application but their performance is better under controlled conditions compared to open fields (Zheng et al., 2022).

3.3.13 Harvesting Time and Techniques

By controlling microclimate, harvesting time can be shifted earlier or later depending on the market requirements. Compared to open field situations, high returns can be earned by providing out of season fruits. Using greenhouse artificial intelligence, proper time of harvest and quality of grapes at any time during production period can be determined accurately and can be matched with the market demand, with a possible error of only 3 days (Alonso et al., 2021). One of the most commonly employed technologies for the said purpose is imaging and machine vision technology. Electronic nose and tongue technology can determine the internal conditions of the fruits and back-propagation neural networks improves the accuracy of the results (Gao et al., 2022). However, their use for grape berries is still very limited (Wei et al., 2022).

3.3.14 Economic Considerations and Potential Returns

Covered structures reduce the cost of chemical sprays by almost 75%, by inhibiting entrance of insect-pests inside the greenhouse. In addition to that, the limited canopy of the vines requires less fertilization and easy management. Interception of sunlight by covering improves color and chemical composition of berries. The calculation of environmental impact conducted through life cycle assessment and the economic evaluation indicate that both the early and delayed production models in greenhouses release the greatest environmental burdens along with the highest economic returns when compared to the conventional harvesting production model (Schwerz et al., 2023).

p-ISSN 2963-1041, e-ISSN 2962-9837
Vol 3.No.2. 2024, pp. 1-14
Availble online
https://journalng.uwks.ac.id/index.php/jnsl

3.3.15 Limitations for Viticulture in Greenhouse

Greenhouse cultivation of grapes entails higher initial investment due to the need for greenhouse construction and purchase of protective materials. It requires meticulous manual work for tasks like flower and fruit thinning and vine management with less mechanization. Additionally, maintaining optimal conditions within the complex greenhouse environment, including humidity and temperature management presents challenges to prevent diseases and fruit deterioration. Consequently, there's a greater demand for labor and elevated technical risks, potentially impacting grape quality and yield (Yoshida et al., 2022). Challenges persist in greenhouse cultivation due to the perennial nature and chilling requirements of table grapes. Small-scale growers face labor shortages and struggle to adopt advanced production technologies, resulting in reduced technical efficiency (Song & Xu, 2023).

IV. CONCLUSION

Due to the continuous climate change, not only the grapevines are becoming weak but the pest attack has also become heavier and more frequent. Due to the complexity of climate, controlling it under open field conditions is impossible. Hence, greenhouse cultivation of grapes can pose a possible solution for the current scenario. Greenhouse grape cultivation techniques should precisely minimize inputs and waste production by efficiently utilizing resources while considering their possible negative environmental effects. Expanding the operations by land transfer and reducing constraints with labor force can be helpful. Professional division of labor and cooperation can lower average cost and enhance economic returns thus achieving an optimal ratio.

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