Article

Climate Change Adaptation Strategies for Grape Cultivation in Yamanashi Prefecture of Japan

Divya Suresh *, Yinjia Zhang, Yuqiu Cao and Rajib Shaw

Graduate School of Media and Governance, Keio University, 5322 Endo, Fujisawa, Kanagawa Prefecture 252-0882, Japan; yinjiazhang07@gmail.com (Y.Z.); yuqiu.cao@keio.jp (Y.C.); shaw@sfc.keio.ac.jp (R.S.)

* Corresponding author. E-mail: divyas@keio.jp (D.S.)

Received: 15 November 2023; Accepted: 27 December 2023; Available online: 9 January 2024

ABSTRACT: Climate change impacts agricultural production, especially fruits. Amongst fruits, the grape is economically valuable and highly affected by climate change. Therefore, climate adaptation strategies are essential in overcoming the detrimental effects of climate change on grape cultivation. The study summarises adaptation strategies for grape cultivation in general and focuses on climate change. The Yamanashi prefecture in Japan is taken for the case study. Our findings indicate a decline in grape production in Japan and Yamanashi prefecture. This is attributed to the effects of climate change. Following this, various support measures (adaptative, mitigation, others) provided by the Yamanashi government towards grape cultivation are summarised and analyzed. The study concludes by offering recommendations by drawing lessons from the literature review on adaptation strategies for grape cultivation, focusing on overcoming climate change impact in the context of Yamanashi prefecture.

Keywords: Sustainability; Local production; Innovation; SMEs; Food tech; Japan

1. Introduction

A growing population is driving the demand for global food production. By 2050 to feed the 9 billion people, the world will need 70% more food. The situation is becoming even more challenging with the climate extremes and uncertainties impacting agriculture extensively. The problem context is two sides of the same coin. While agriculture faces negative impacts from climate change, it is also a driver of greenhouse gas emissions as it contributes 19–29% of the total emissions [1].

According to Japan's Cabinet Office 2021 statistical data, the Japanese aging population rate is 28.8%, the highest in the world [2]. At the outset of Japanese economic and social growth, the number of workers in the agriculture sector and the GDP share of the agriculture and allied industries have been drastically shrinking. Employed persons in the agricultural field dropped to 2.13 million in 2020 (3.2%) from 5.77 million in 1980 (10.4% of the total employed persons). Adding to the problem is insufficient youth participation in the agriculture sector, who perceive the work to be highly labor-oriented but low-income. Conversely, agriculture's share of GDP reached 1.0% in 2020 from 3.6% in 1980. Also, the cultivable land area had shrunk drastically from 6.09 million hectares in 1961 to 4.35 million in 2021 [3]. According to the Ministry of Agriculture, Forestry, and Fisheries, in 2017, Japan could only produce 38% of food consumed on a calorie basis.

With Japanese agriculture facing many such problems, the need of the hour would be to develop technologies that will efficiently save labor and minimize resource utilization to meet the food demand through sustainable agriculture. In 2020, the Japanese government declared carbon neutrality through its green growth strategy by 2050, which includes achieving zero carbon emissions from the agriculture, forestry, and fisheries industries [4]. Climate Smart Agriculture is an integrated approach to solving the climate problem and attaining sustainable food security by inculcating increased productivity, enhanced resilience, and reduced emissions while relying primarily on existing knowledge [1].

https://doi.org/10.35534/rrd.2024.10001

The Japanese government encourages innovative agricultural practices with nationwide project initiatives [5,6]. Japanese government official considers raising farmers' income crucial in reviving Japan's 9.3 trillion-yen farming industry. In addition, there is a focus on improving the export of high-quality Japanese fruits, as there is a high demand in the foreign market, especially the Asia-Oceania market. This is anticipated to stabilize farmers' income.

Vegetables, fruits, and flowers constitute horticultural crops and contribute to 40% of Japan's agricultural produce. It has been reported that 85% of new farmers are attracted to horticulture cultivation as there can be turnover with high-value-added products [7]. Japan is facing the impact of global warming due to climate change. Its temperature has risen by 1 degree Celsius over the last century. The temperature changes in Japan have already impacted Japanese agriculture in many ways. Looking at the Hokkaido region, global warming has positively impacted rice cultivation; conversely, it has negatively impacted fruit cultivation. For instance, the color of grapes had not turned to its usual red, and peaches with brown flesh [8]. Skin coloration is an important attribute that determines the quality of fruits. The temperature changes due to global warming adversely impact the color of the fruit during its skin coloring and development stage. The abnormal coloration in grapes is because anthocyanin formation is affected by high temperatures, affecting the quality of fruits [9]. In addition, there is a clear temperature response not only during the growing season but also during the dormant season, which means that fruit trees are affected by global warming all year round [10].

According to a survey conducted by the National Agriculture Food Research Organization (NARO) to study the impacts of climate change on Japanese agriculture, 100% of respondents from all 47 prefectures reported an effect on fruit cultivation, while 90% on vegetables and flowers, 70% on paddy rice cultivation and only 40% on wheat, soybeans, and livestock. Research studies have highlighted the importance of adaptation techniques against temperature changes, especially for fruits. This is of high importance when we focus on the economic viability of fruit cultivation wherein fruit trees are not transplantable, the sowing window cannot be changed, and the same tree produces for a decade, unlike other crops [11]. Therefore, the effects of climate change are likely to accumulate within the trees.
From that respect, the current study tries to address the following research question:

1. How does climate change impact grape production in Japan and Yamanashi?
2. What are the support and policy measures the Yamanashi government provides to overcome climate change's impact on grape production?
3. Evaluating the current measures of the government and drawing lessons from the literature review, what strategies could further help grape production for adaptation to climate change?

This paper identifies the impact of climate change as a crucial factor in affecting agricultural produce, especially fruits and grapes. More specifically, the study highlights the growing need to adopt suitable adaptation strategies as a countermeasure to the climate crisis. Taking the case of Yamanashi prefecture in Japan, it was analyzed how, over the years, there has been a decline in grape production and a shrinking in acreage. The study identifies that the frequent and unpredictable weather conditions, including typhoons, floods, continuous rainfall, insufficient sunshine, and strong winds in Yamanashi, has been detrimental to grape cultivation, resulting in discoloration of sunburned and disease-infested grape. The study concludes by providing a few recommendations to cope with climate change for grape cultivation.

2. Approach and Methodology

To address the research question mentioned above in the introduction section, firstly, an online literature review search was performed. Yamanashi prefecture in Japan was chosen for the case study as it is an essential fruit-producing region. Fruits like grapes, peaches, and plums are widely grown in the area. Considering the high economic importance of grapes and also because it belongs to the fruit category that is significantly affected by global warming, Grape was selected for the study. The research aimed to identify any gap in the promotion of climate-resilient measures by the Yamanashi government toward grape cultivation in the region.

The keywords used during the literature review and online tracking of articles and websites are as follows: climate change impact on fruits, climate change impact on Grapes, Adaptation strategies for Grape cultivation, Yamanashi Grape cultivation. Thousands of articles, research papers, Japanese government reports, and other technical reports appeared during the search. Japanese Language reports were selected based on their suitability to research objectives. The inclusion criterion was set in two stages. In the first step, abstracts were read, and articles were placed on the waiting list. The papers were later prioritized after reading them in their entirety to decide if it has to be selected or discarded. Then, the articles were saved in the free online referencing software Mendeley. For the final study, 30 articles that met the below criterion were selected for analysis.

I. (ALL = (Climate Change))
II. AND (ALL = (FRUITS)) OR (ALL = GRAPES)))
III. AND (ALL = (Climate change Adaptation Strategies)
IV. AND (ALL = (JAPAN)) OR (ALL = YAMANSHI)))

The study provided significant insights into grape cultivation in Yamanashi prefecture and the support measures undertaken by its government in addressing the impacts of climate change on grape production. This helped identify steps that could be further taken in this context. There are four sections in the research paper. The first section discusses fruit farming in Japan and smart agricultural practices, the impact of climate change on grape cultivation, and adaptation strategies for the grape to climate change under literature review. The second section justifies choosing Yamanashi prefecture in Japan as the study area. The third section analyzes the declining trend of grape production in the context of Yamanashi and Japan and the support measures for grape cultivation taken by the Yamanashi Government. Finally, the study concludes by providing recommendations and emphasizing the importance of applying adaptative strategies for grape cultivation to cope with climate change.

3. Literature Review

3.1. Fruit Farming in Japan & Smart Agricultural Practices

Fruit farming is highly labor extensive work. Against the background of Japanese agricultural labor shortage, most work, such as seedling cultivation, planting, monitoring, harvesting, and shipping, is done manually in horticulture. For example, compared to rice cultivation, strawberry farming would need 2019 hours per 10 a., which is 80 times that of rice [12].

Deploying innovative technologies in horticulture looks to have a promising future and is also a solution to address labor shortages. Next-generation horticulture will use smart farming technologies and is expected to evolve into an automated and optimized system ranging from seedling cultivation to a supply chain. The trend in greenhouse horticulture is toward smart greenhouse farming. Smart greenhouses are calibrated to provide nearly accurate data readings with the help of sensors and IoT. The data can help customize the amount of water, light, and carbon dioxide needed for the plants. The fruitfulness of deploying smart greenhouses has been evident from large harvests and high-quality fruits [13].

The application of Robots in weeding, crop monitoring, yield estimation, harvesting, and in-field transportation has been researched extensively and identified to have potentials and shortfalls that must be addressed. Artificial intelligence is deployed for transforming data into information that can be helpful to fruit growers to make informed decisions.

A research study [14] about persimmon fruit cultivation in Nara points out a reduction in labor and work time, an increase in farm income, and high-quality fruits while implementing smart farming machinery during various stages (weeding, pest control, harvesting) of the farming. However, the research gap mentioned is to identify the economic validity of introducing such innovative farming machinery.

3.2. Impact of Climate Change on Grape Cultivation

As depicted in Figure 1, a fruit tree is classified under two types based on global warming and its effect on fruits.

Type 1: Earlier development type (pears, peaches, and apricots). In these species, global warming has expedited both flowering and fruit maturation processes.

Type 2: Prolonged development type (apples, persimmons, and grapes). For these, global warming has only hastened the flowering stage, without affecting the duration of fruit development [15].

Trees where flowering and harvesting are accelerated due to temperature change fall under the earlier development type. This is indicated in Figure 1. though two red arrows, which implies flowering and maturation had accelerated. On the other side, fruit trees like grapes whose flowering cycle is accelerated due to temperature change, but harvesting does not come under prolonged development type. This is also indicated in Figure 1 through one red arrow mark, which implies flowering has only accelerated. Research evidence and results show that the impact on the fruit quality of the prolonged development type (grape, persimmons, apples) is more prominent than those of the earlier development type.

Grape is also one of the most important fruits in the world economically. It has the most extensive acreage when compared to other fruits. The production and quality of grapes can be affected by environmental factors such as high temperature making it the fruit highly susceptible to climate change [16]. Climate change also affects grape cultivation through the entire lifecycle of the plant: budding, flowering, grape set, and maturing can happen early, the complete management process is hit, the impact of pests and diseases, the immune response of the plant, etc. The effects of high temperatures on grapes include poor coloration, delayed coloration, sunburned grapes, the occurrence of damaged grapes, poor germination, frost damage, and cracked grapes.

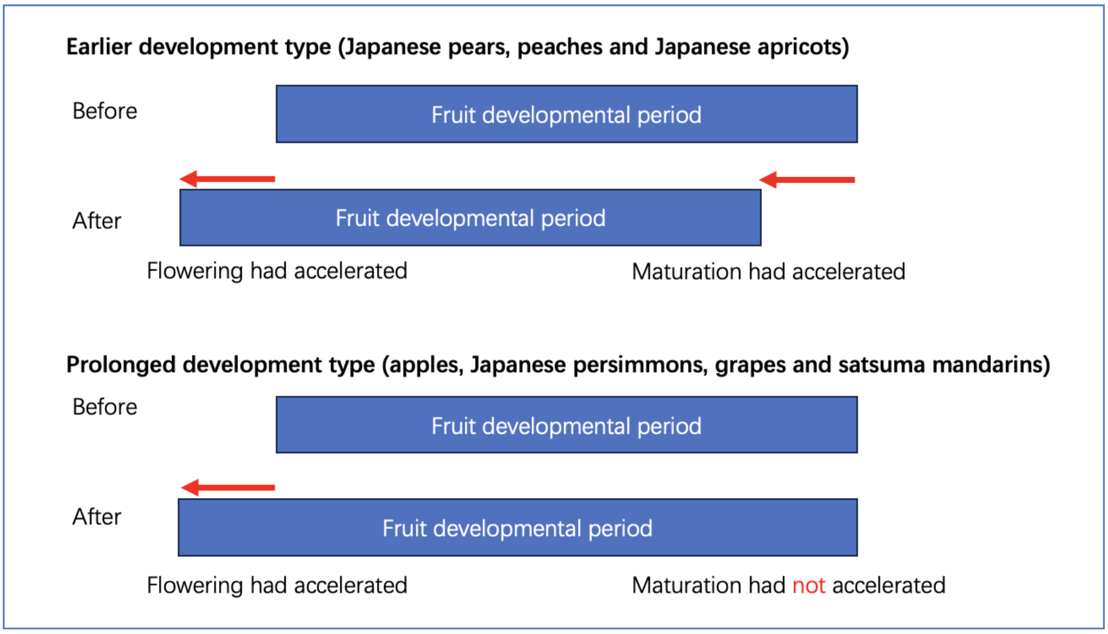

Figure 1. Tree species have been classified into two types based on the responses of fruit development to recent warming trends. By authors, from source: [15].

The quality of grapes can be affected in the following ways: high sugar content, low acidity, the authentic taste of the fruit, and discoloration problems [17]. In particular, the deterioration of appearance quality affects the selling price, leading to a decline in growers' income and the production area brand, so adequate measures are required [18].

Against climate impacts and extreme weather events, climate-smart practices and technologies for risk reduction focusing on grapes, as recommended by Food and Agricultural Organizations of the United Nations, is to protect the crop with greenhouses encompassing simple structures, helping for an early or late harvest as suitable. This method has been implemented, and benefits have been reaped in Sicily and Puglia, Italy [19].

3.3. Adaptation Strategies for Grapes to Climate Change

The paper [20] discusses the impacts of climate change on viticulture. On the other hand, [21] discuss the various adaptation strategies employed worldwide for vineyard cultivation against climate change. The adaptation strategies are classified into short-term and long-term. Water status, phenology, yield, berry composition, and freshwater ecosystem are the five main outputs on which the effects of the adaptation levers could be categorized. Short-term adaptations include soil, canopy, Irrigation, Harvest, and post-harvest management. Long-term adaptations are vineyard design, plant material, farm strategy, and site selection. There are positive and negative aspects to each of the adaptation strategies. Therefore, a mix of short-term and long-term adaptation strategies is recommended. The mix should be based on the local environmental conditions and opportunities.

In [15], the adaptation of fruit trees to climate change has been discussed under three stages.

Stage 1: Avoidance and tolerance of high temperature through the use of production technology

Stage 2: Cultivar selection and breeding

Stage 3: Movement of Production areas

Under Stage 1, the temperature of the fruit can be controlled by controlling the temperature of the tree itself. Fruit trees like grapes develop color before mid-summer. The two long-term adaptive measures against discoloration for grapes grown in an open field, such as cultivation under cover and using a superior-color cultivar, all results in the phenological shift. By implementing plastic greenhouses, we can induce a coloring period in grapes by creating a low-temperature situation. This is considered an effective technique in causing coloring in grapes [22]. Girdling is another technique whereby fruit color can be increased by boosting photosynthesis pigments in fruits without impacting the number of fruits per tree field [23].

Under Stage 2, some new cultivars of grapes adapted to warming that has been developed are "Queen Nina," "Gross Krone," and "Shine-muscat" without coloring problems. And under Stage 3 it is predicted to move the cultivation of citrus fruits, persimmons, and grapes from the current sloping lands to higher altitudes in the future.

Ref. [24] Provides a comprehensive review of various adaptation techniques focusing on delaying grapevine ripening, as it is the main detrimental effect because of climate change faced by grape cultivators. It states that adopting a combination of more than one adaptation strategy to just practicing one will help delay the ripening process from a few days to a few weeks. Ref. [25] reviews the effect of climate change on grape's phenology, physiology, and biochemistry. Moving to higher altitudes for grape cultivation has been proposed as an adaptation strategy after thoroughly evaluating and examining climate change's positive and negative effects on grape production at higher altitudes. Ref. [26] Highlights the need for winemakers to resort to environmentally sustainable cultivars to traditional cultivars. The importance of developing and adapting to new cultivars that exhibits resistance and climate change adaptation. Ref. [27] presents ecophysiological modeling and advancing knowledge of genetic traits as critical factors for successfully adapting grape cultivation to climate change. Ref. [28] supports employing smart technologies such as Artificial intelligence, different sensing technologies, and robots to make more informed decision-making processes and mitigate climate change in grape cultivation. It presents various case studies that prove such practices are environmentally and economically sustainable. Also, the outcome of such practices shows socio-economic benefits for grape cultivators at all scales by managing efficiency, reducing input costs, and, ultimately, a better product. Ref. [29] presents a research gap and encourages future research to focus on optimizing the profitable and sustainable production of high-quality grapes, addressing important climate change issues, global competition, and shifting consumer preferences. [21] observed that regarding evaluating strategies for adaptation to climate change in grape cultivation, climate data sources were not appropriately considered, and climate uncertainty was not considered mostly. Additionally, the paper highlights a research gap in assessing the economic impacts of adaptation at the farm scale.

4. Study Area

4.1. Yamanashi Prefecture and Grape Cultivation

Fruit farming, including grape farming, is the core of the agricultural produce in the Yamanashi region. Table 1 below details fruit ranking in Yamanashi prefecture based on their yield against the national output. Fruits like grapes, peaches, plums, and karin hold the first position. Grape holds the first rank in Yamanashi, with a harvest amount of about 41,800 tons, 23.93% of the total national yield.

Figure 3 below provides details of grape production in Yamanashi prefecture [30] during the last ten years and its corresponding cropping acreage. The production details are marked with time (2011–2020) on the x-axis, while the hectare land area is plotted over the y-axis.

Figure 2. Location of Yamanashi prefecture in Japan. Source: [30].

Table.1. Ranking of Fruits in Yamanashi Prefecture. Source: [31].

Rank	Fruit Name	Yield	Percentage (Share)	National Yield
First place	Grapes	41,800 tons	23.93%	174700 tons
First place	Peaches	39,400 tons	34.81%	113200 tons
First place	Plum	7820 tons	33.85%	23100 tons
Third place	Cherries	1080 tons	5.97%	18100 tons
Third place	Nectarine	205 tons	12.22%	1678 tons
Fourth place	Karin	19 tons	20.54%	92.5 tons

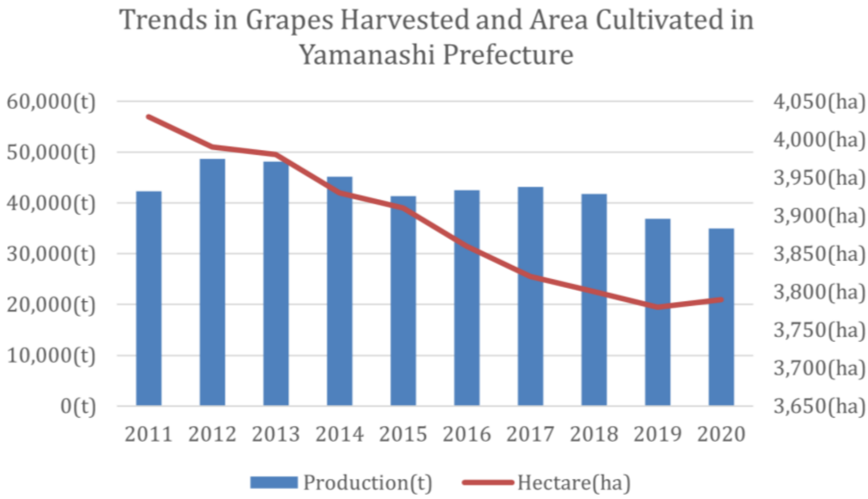

Figure 3. Trends in Grapes Harvested and Area Cultivated in Yamanashi Prefecture. By authors, with source: [32].

Figure 4 below helps visualize the contribution of Yamanashi prefecture's grape production against Japan's grape production during the last ten years. Yamanashi's grape production ratio is marked with time (2011–2020) on the x-axis, while the hectare land area is plotted over the y-axis, and the bar graph represents Japan's contribution.

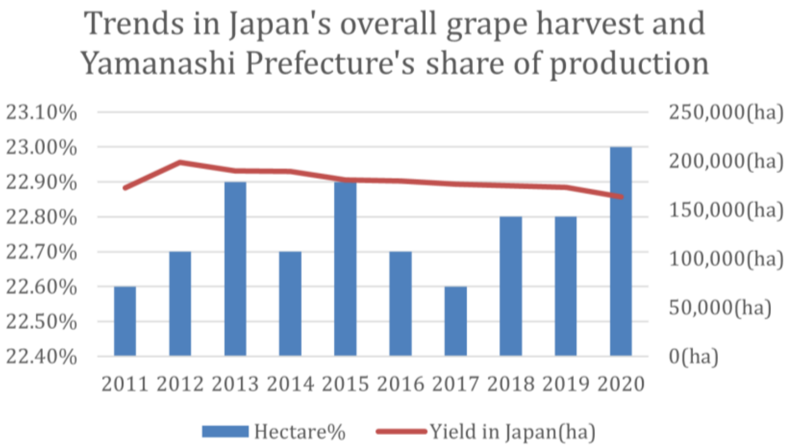

Figure 4. Trends in Japan's overall grape harvest and Yamanashi Prefecture's share of production. By authors, with source: [32].

Yamanashi is also important with its significant contribution to the wine-making industry in Japan. In addition, it is the top wine region and is famous for its wine tourism, as shown in Figure 5.

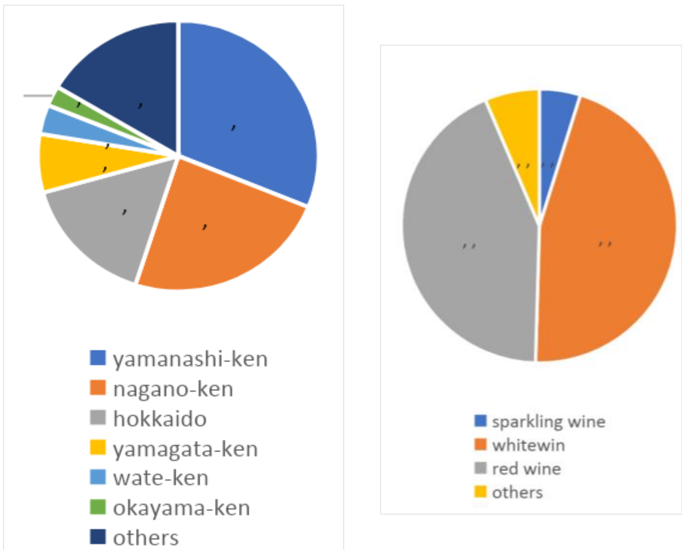

Figure 5. Production volume of Japanese wine by type and composition ratio of the top 6 prefectures. By authors, with source [33].

4.2. Different Varieties of Grapes in Yamanashi Prefecture

Table 2 presents five varieties of grapes that have been experimented with and registered by the Yamanashi Fruit Tree Experimentation Institute in the past, as well as their hybrid combination and characteristic.

Table 2. Different Varieties of Grapes in Yamanashi Prefecture. By authors, with source [34].

Grape	Variety	Hybrid Combination	Characteristic
	Kai Bran	Koshu × Pinot Blanc	Cold resistance
	Sansemillon	Fuefuki × Semillon (Glow Semillon)	Cold resistance
	Fuefuki	Mills × Angelo Pilobano	The yield is 2.2t or more per 10a Very productive
	Neo Alicant	Delaware × Bailey Alicant	cold resistance and disease resistance
	Kai Mirei	Red Queen × Koshu Sanshaku	Shelf life is very good.

5. Results and Discussions

5.1. Declining Grape Production in Japan

The statistical data on grape cultivation and production in Japan from the Ministry of Agriculture, Forestry and Fisheries reveal that there has been a severe decline in terms of cultivation area, harvested volume, and shipment volume over the years since 1973 [35] which is presented in Figure 6a–c.

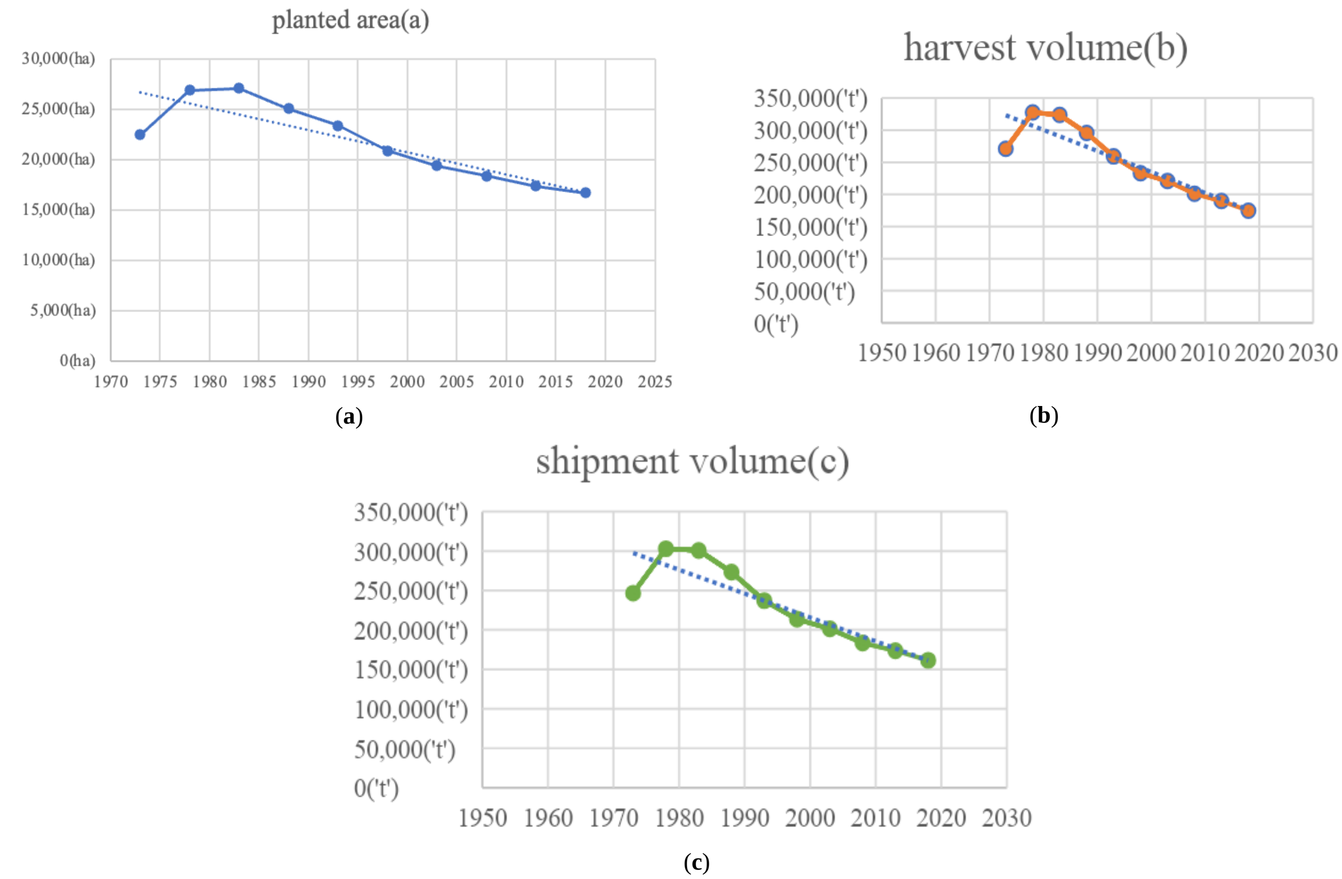

Figure 6. Planted area, harvested volume, and shipment volume over the years since 1973. Source: [35].

Additionally, evidence from studies shows that the average grape cultivation area per household has only slightly increased from 34a in 2000 to 40a in 2015. As a result, Japanese grape farmers have found it challenging to increase their income profits by increasing the scale of grape cultivation. Instead, they have selected grape breeds priced better and easy to cultivate [36].

Between 2005 and 2015, it was observed in Japan that along with a declining number of fruit-growing farmers, there was an increase in the number of farmers over 60 years of age practicing fruit farming. The statistics depict that fruit tree farmers decreased by 20%, while farmers aged 60 and over increased by 16% points and reached 80% [37]. As discussed in Section 3.1, since fruit farming is highly laborious work and the work hours incurred in fruit cultivation are exponentially higher than other agricultural produce such as rice, this could be the evident reason for the decline in grape farmers and cultivation areas in Japan. Though studies point out the merits of deploying innovative technologies like smart greenhouse horticulture, their economic viability and ease of adoption amongst aging farmers must be facilitated.

The Ministry of Agriculture, Forestry, and Fisheries (MAFF) has conducted a survey from time to time on the effects of climate change and global warming on agricultural products. While looking at the impact of global warming on fruits, especially grapes, during the year 2021, the findings are as below: [38]

- Poor and delayed coloring was the most severe reported problem
- During rainy days in summer, sunburned grapes and cracked fruit due to heavy rainfall were the reported concerns.
- Very similar concerns have found to be reported in the year 2020 as well.

According to the 2017 and 2021 global warming impact study reports, Table 3 represents climate change's effect on grape production.

The significant phenomenon reported is the discoloration of grapes, sunburned, cracked, and not matured grapes. Based on these affected categories and the leading cause, such as high rainfall, low rainfall, and high temperature, the number of prefectures impacted throughout Japan is presented from 2017–2021.

Table 3. Climate change's effect on grape production. By authors, with source: [39].

Current Climate Change Impacts	2014	2015	2016	2017	2018	2019	2020	2021	Effect on Quality and Yield	Main Cause
Poor coloration, delayed coloration	6	12	15	25	22	20	20	20	Decline in quality and yield	High temperatures and heavy rainfall during fruit ripening and harvesting period (June-September)
Sunburned grapes	4	4	5	1	7	7	6	8	Decline in quality and yield	High temperatures and less rainfall during fruit ripening and harvesting period (June-August)
Cracked grapes	2	1	–	1	1	0	6	5	Decline in quality and yield	Heavy rainfall during fruit ripening and harvesting period (July-September)
Poor germination	1	2	3	2	0	1	2	2	Decline in quality and yield and Variation in timing of agricultural work	Lack of low-temperature exposure due to high temperatures during dormancy and germination period (October-January)
Frost damage	–	–	–	1	1	1	1	2	Decline in quality and yield	Low temperatures from germination to leaf unfolding period (March-April)

5.2. Declining Grape Production in Yamanashi

Observing the past ten-year trend, grape production and cultivation have decreased by 18% and 4% in the Yamanashi Prefecture. The report [40] attributes the decline in grape production volume in Yamanashi prefecture to two main reasons. Firstly, lack of successors to continue grape cultivation and the aging proportion of farmers. Both factors are because of the changes in the sales environment, continued decreased farm income, and increased management costs. Secondly, recent climatic events in Yamanashi prefecture, like heavy snowfall in 2014 or the hailstorm in 2022, have been mentioned as the reasons for causing diseases in grapes like bacterial disease and grape late rot, significantly affecting the production volume. Also, the annual mean temperature of Yamanashi prefecture has gradually been increasing over the years, as shown in Figure 7. As discussed in Section 3.2, grape falls under the prolonged development type of fruit, which is the most impacted by global warming and increasing temperature. The grape is affected through the entire lifecycle because of climatic stressors; as a result, not only the appearance of the fruit but the quality of the fruit deteriorates. Additionally, damage caused by wild birds and animals in the mountainous area of Yamanashi prefecture has also been listed as the reason.

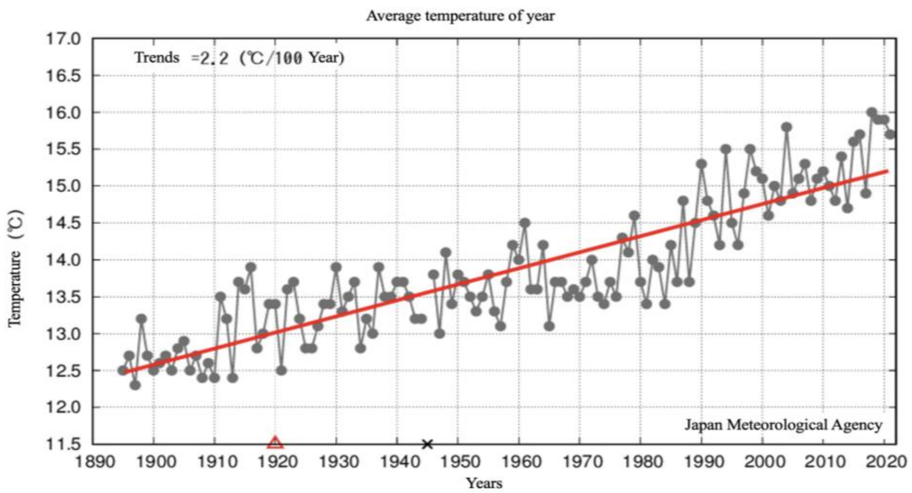

Figure 7. Average temperature of Yamanashi. Source: [41].

5.3. Support Measures for Grape Cultivation – Yamanashi Government

The Yamanashi government has introduced support measures such as consultation, loans, subsidies, etc., to meet the needs of the farmers who are just about to start cultivating wine grapes, medium and small-sized wineries in the prefecture. Furthermore, to tackle the various problems such as climate change and its effects on fruits, such as affected grape quality, the various support measures taken by the Yamanashi government are enlisted as below:

(1) Strengthen the Yamanashi brand.
(2) Strengthen the production base for high-quality fruits
(3) Strengthening the ability to respond to risks such as disasters and pests
(4) Securing and cultivating business leaders
(5) Promoting the sixth industrialization Promotion

In 2020, Yamanashi Prefecture became Japan's first to participate in the United Nations "4 per mill initiative", a mitigative measure against climate change and global warming. The 4 per mill initiative was introduced to encourage growers to sequester carbon in the soil, thereby significantly nullifying the carbon dioxide emitted to the atmosphere. The initiative was first conceptualized in 2015 when it was introduced at COP21(the 21st Conference of the Parties to the United Nations Framework Convention on Climate Change. As of September 2022, 623 countries, including Japan, have tuned out to be participants in the 4 per mill initiative. The initiative is targeted to increase the amount of carbon in the soil by 4 per mil (0.4%) every year, substantially reducing the amount of carbon dioxide emitted into the atmosphere due to human economic activities to virtually zero [42].

The Yamanashi prefectural government has been focusing on adaptative measures against the impact of climate change on grape production, including developing new breeds and technologies to respond to climate change. The Yamanashi Prefectural Fruit Tree Experiment Station participated in the project involving developing new grape varieties that are early breeding. The new types introduced are "Colline Welt," an early white wine grape variety in response to the damages caused by typhoons, and "Ryouka," a grape variety with good coloring that withstands high temperatures [43].

The other existing smart agricultural practices in the Yamanashi region for Grape cultivation use an AI forecasting kit to predict agricultural disease outbreaks. This has been effective in controlling pests and using minimum pesticides. In addition, drones are being used to spray pesticides on grape trees. This is observed as an effective way to deal with the labor shortage. As discussed in Section 3.3, deploying smart technologies like AI could address the multifaceted problems in grape cultivation, such as labor shortage, climate change, and environmentally and economically sustainable decision-making. This can also fetch socio-economic benefits for the grape cultivators by enabling a reduction in input and management costs and resulting in a better product.

6. Recommendation

To have more grape producers adapt and practice climate-related technological intervention, the facets of the solution should be affordable, rapid, simple, accurate, precise, and integrated with data-gathering platforms. In other words, we need a few minimum requirements for maximum adoption [44].

The climate trend in the Yamanashi prefecture denotes frequent and unpredictable weather conditions, including typhoons, floods, continuous rainfall, insufficient sunshine, and strong winds, all affecting agricultural produce, particularly grape production. These necessitate an increasing need for reliable and precise climate and ecological data for grape producers to devise appropriate adaptation strategies toward grape cultivation.

Though climate-smart technology-oriented practices exist among significant players, it is not widespread. For example, in the case of an AI forecasting kit developed by Yamanashi University Wine Science Research Center in collaboration with a few local wineries, it has been reported that more data will help better forecasting. However, more data will be available only when more grape producers participate and adopt such practices [45]. On the other hand, in small family-run farms, the aging and declining farming population are practicing manual farming methods. Though current agricultural research focuses on solving aging and labor issues by introducing drones and robots in fields, which is essential, climate-friendly strategies-oriented research is often overlooked. This is also evident from the case of the Japanese government's Smart Agricultural Demonstration Project, which addresses the impact of climate change. However, when the actual demonstration is implemented in each prefecture, the focus is more on technologies to address the labor shortage and the aging population. So, it is critical to widely put climate change-related adaptation strategies into the solution. Furthermore, with Japan having a strong digital backbone for growth in the agriculture sector, further efforts need to be taken to promote smart agriculture (AI, IoT, Robots). The IoT-based agricultural system could automatically measure weather parameters using sensors and discover diseases in the grapes. The system could send alerts about weather conditions information on farmers' mobile, and farmers could pick adaptation strategies accordingly. Compared to the greenhouse with no sensors, the IoT-based greenhouse system for grapes could be the solution for addressing many problems in the Yamanashi grape cultivation scenario. [46] Implementing such systems could potentially help improve yield and productivity against the labor shortage scenario, improve fruiting under controlled temperatures, and increase customer visual appeal. Other issues to be addressed are ensuring rapid adoption of such hi-tech amongst aging farmers, data ownership, and security issues. The IoT-based agricultural system for grapes will not only solve product quality and help mitigate the effects of climate change but also provide socio-economic benefits, addressing reduction in input costs and improved efficiency and better-quality products. This could also attract young people to pursue grape cultivation [47,48].

In the Yamanashi scenario, more focus is given to developing grape varieties that better meet consumer demands, high-quality fruits, and the Yamanashi brand. The huge morphological and physiological differences in grape cultivars permit grape cultivation over a wide range of climates. Exploring and developing cultivars that exhibit resistance to diseases and climate change adaptation could be helpful [49].

Finally, as discussed in the literature section in 3.3, the way forward would be to focus on sustainable grape cultivation addressing climate change issues, global competition, and shifting consumer preferences. In this regard, a simple and effective solution could be improving international and regional collaboration between other grape producers on climate-smart best practices in grape production.

7. Conclusions

A literature review was performed to understand the effects of climate change on grape production and various adaptative strategies for overcoming the impact of climate change on grapes. The grape production trend was examined in the Yamanashi prefecture identified for the case study. Grape was chosen for the study considering two factors since the fruit falls under the prolonged development type. The fruit quality is affected significantly due to climate change factors and the fruit's high economic importance. Yamanashi Prefecture was taken for the observations considering its significance and leading contribution to fruit farming and wine-making in Japan. Yamanashi government has been instrumental in introducing and implementing regional revitalization policies targeting grape cultivation. The activities range from developing superior varieties of grapes that best meet consumer needs, protecting old trees through its fruit tree management support project, serving the demanding overseas markets by channelizing production, distribution, and selling grapes through an integrated framework. In addition, the Yamanashi government has also focused on tackling the impact of climate change on grapes by promoting rain shelters and heated greenhouses for stable production and high profitability.

The government focuses more on mitigative strategies than adaptative and labor-saving technologies compared to climate-resilient technologies. Also, grape farmers in Japan select grape breeds based on profitable varieties to climate-resilient ones.

Therefore, a few suggestions in this study to tackle the impact of climate change on grape production are investing in climate-related technological intervention and adaptation strategies, plant-based town development, and international and regional collaborations amongst grape producers.

Acknowledgments

The first author is thankful to Japan Science and Technology (JST) for the scholarship supporting Ph.D. research.

Ethics Statement

Not applicable.

Informed Consent Statement

Not applicable.

Declaration of Competing Interest

The authors whose names are listed immediately below report that the authors have no conflicts of interest to declare. Authors also declare no financial interest to report and certify that this work is not under review at any other publication.

Data Availability Statement

The authors confirm that the data supporting the findings of this study are available within the article [and/or] its supplementary materials.

References

1. The World Bank. Climate-Smart Agriculture. 2023. Available online: https://www.worldbank.org/en/topic/climate-smart-agriculture (accessed on 12 February 2023).
2. Cabinet Office Japan. Annual Report on the Ageing Society [Summary] FY2021. July 2021. Available online: https://www8.cao.go.jp/kourei/english/annualreport/2021/pdf/2021.pdf (accessed on 12 February 2023).

3. Statistics Bureau of Japan. Statistical Handbook of Japan 2022. Available online: https://www.stat.go.jp/english/data/handbook/pdf/2022all.pdf (accessed on 12 February 2023).
4. Ministry of Economy, Trade and Industry. Green Growth Strategy Through Achieving Carbon Neutrality in 2050. Available online: https://www.meti.go.jp/english/policy/energy_environment/global_warming/ggs2050/index.html (accessed on 12 February 2023).
5. Ministry of Agriculture, Forestry and Fisheries. Smart Agriculture Promotion Forum 2020. Available online: https://www.maff.go.jp/j/kanbo/smart/forum/R2smaforum/index.html (accessed on 12 February 2023).
6. Yasuoka S. Promotion of "Smart Agriculture." *J. Robot. Soc. Jpn.* **2017**, *35*, 362–365.
7. Ministry of Agriculture, Forestry and Fisheries. Situation of Greenhouse Horticulture. February 2018. Available online: https://www.maff.go.jp/e/policies/agri/attach/pdf/index-15.pdf (accessed on 12 February 2023).
8. Michael Case & Andrea Tidwell. Nippon Changes Climate Impacts Threatening Japan Today and Tomorrow. 2008. Available online: https://www.wwf.or.jp/activities/lib/pdf_climate/environment/WWF_NipponChanges_lores.pdf (accessed on 12 February 2023).
9. Shinomiya R, Fujishima H, Muramoto K, Shiraishi M. Impact of temperature and sunlight on the skin coloration of the 'Kyoho' table grape. *Sci. Hortic.* **2015**, *193*, 77–83.
10. Sugiura T. Influence of global warming on fruit tree production environment and research problems. *J. Agric. Res.* **2002**, *24*, 23–30.
11. Ministry of Agriculture, Forestry and Fisheries. *Impact of Global Warming on Agriculture, Forestry and Fisheries and Possible Countermeasures in Japan*. 2007. Available online: https://www.affrc.maff.go.jp/docs/e/attach/pdf/Data2-1.pdf (accessed on 12 February 2023).
12. Noboru Noguchi. *Supporting the Future of Foods: Japan's Smart Agriculture*. July 2022. Available online: https://nextrendsasia.org/supporting-the-future-of-foods-japans-smart-agriculture/ (accessed on 12 February 2023).
13. Ichigo. *The Smart Greenhouses of Miyazaki*. June 2019. Available online: https://www.ichigo.gr.jp/en/esg/initiatives/community/20201008204249.html (accessed on 12 February 2023).
14. Yamamoto A, Kusudo T, Kimura M, Matsuno Y. Performance Assessment of Farm Machinery for Persimmon Fruit Cultivation in a Japanese Mountainous Area. *AgriEngineering* **2022**, *4*, 17–31.
15. Sugiura, T. Three climate change adaptation strategies for fruit production. Climate Smart Agriculture for the Small-Scale Farmers in the Asian and Pacific Region. 2019: 1096. Available online: https://www.naro.go.jp/english/laboratory/niaes/files/fftc-marco_book2019_277.pdf (accessed on 12 February 2023).
16. Mozell MR, Thach L. The impact of climate change on the global wine industry: Challenges & solutions. *Wine Econ. Policy* **2014**, *3*, 81–89.
17. University of Reading. *Effects of Climate Change on Growing Grapes*. FutureLearn. Available online: https://www.futurelearn.com/info/courses/climate-smart-agriculture/0/steps/26593 (accessed on 13 February 2023).
18. Ministry of Agriculture, Forestry and Fisheries. *Climate Change Adaptation Guide for Grape Production*. 2020. Available online: https://www.maff.go.jp/j/seisan/kankyo/ondanka/attach/pdf/index-145.pdf (accessed on 13 February 2023).
19. The Food and Agriculture Organization. *Climate-smart Crop Production Practices and Technologies*. Available online: https://www.fao.org/climate-smart-agriculture-sourcebook/production-resources/module-b1-crops/chapter-b1-2/en/ (accessed on 13 February 2023).
20. Mosedale JR, Abernethy KE, Smart RE, Wilson RJ, Maclean IMD. Climate change impacts and adaptive strategies: Lessons from the grapevine. *Glob. Change Biol.* **2016**, *22*, 3814–3828.
21. Naulleau A, Gary C, Prévot L, Hossard L. Evaluating Strategies for Adaptation to Climate Change in Grapevine Production–A Systematic Review. *Front. Plant Sci.* **2021**, *11*, 607859.
22. Sugiura T, Shiraishi M, Konno S, Sato A. Assessment of deterioration in skin color of table grape berries due to climate change and effects of two adaptation measures. *J. Agric. Meteorol.* **2019**, *75*, 67–75.
23. Yamane T, Shibayama K. Effects of Changes in the Sensitivity to Temperature on Skin Coloration in 'Aki Queen' Grape Berries. *J. Jpn. Soc. Hortic. Sci.* **2006**, *75*, 458–462.
24. Gutiérrez-Gamboa G, Zheng W, Martínez de Toda F. Current viticultural techniques to mitigate the effects of global warming on grape and wine quality: A comprehensive review. *Food Res. Int.* **2021**, *139*, 109946.
25. Arias LA, Berli F, Fontana A, Bottini R, Piccoli P. Climate change effects on grapevine physiology and biochemistry: Benefits and challenges of high altitude as an adaptation strategy. *Front. Plant Sci.* **2022**, *13*, 835425.
26. Töpfer R, Trapp O. A cool climate perspective on grapevine breeding: climate change and sustainability are driving forces for changing varieties in a traditional market. *Theor. Appl. Genet.* **2022**, *135*, 3947–3960.

27. Duchêne E, Huard F, Pieri P. Grapevine and climate change: what adaptations of plant material and training systems should we anticipate. *J. Int. Sci. Vigne Vin* **2014**, 59–67.
28. Tardaguila J, Stoll M, Gutiérrez S, Proffitt T, Diago MP. Smart applications and digital technologies in viticulture: A review. *Smart Agric. Technol.* **2021**, *1*, 100005.
29. Keller M. Managing grapevines to optimise fruit development in a challenging environment: a climate change primer for viticulturists. *Aust. J. Grape Wine Res.* **2010**, *16*, 56–69.
30. Japan-map. Map of Japan. Available online: https://japan-map.com/nihonchizu-hakuchizu-english (accessed on 8 January 2024).
31. Fruit Navigator. Ranking of Fruits in Yamanashi Prefecture. Available online: https://www.kudamononavi.com/graph/pref/pr=19 (accessed on 12 February 2023).
32. Statistics of Japan. e-Stat Is a Portal Site for Japanese Government Statistics. Available online: https://www.e-stat.go.jp/en/ (accessed on 13 February 2023).
33. National Tax Agency. Overview of Domestically Produced Wines (Year 2018 Survey). 2020. Available online: https://www.nta.go.jp/taxes/sake/shiori-gaikyo/seizogaikyo/kajitsu/pdf/h30/30wine_all.pdf (accessed on 13 February 2023).
34. Yamanashi Prefecture. Varieties Registered in the Past. Available online: https://www.pref.yamanashi.jp/kajushiken/103_016.html (accessed on 13 February 2023).
35. Fruit Navigator. Fruit Production Ranking. Available online: https://www.kudamononavi.com/graph/sh=1 (accessed on 13 February 2023).
36. Ayano Fukuda. Major Grape Varieties and Imports with Notable Changes. 2018. Available online: https://www.nochuri.co.jp/report/pdf/nri1807re1.pdf (accessed on 13 February 2023).
37. Ministry of Agriculture, Forestry and Fisheries. Current Status and Issues Related to Fruit Tree Agriculture. 2018. Available online: https://www.maff.go.jp/j/council/seisaku/kazyu/r01_1_kajyu/attach/pdf/index-19.pdf (accessed on 13 February 2023).
38. Sugiura T, Shiraishi M, Konno S, Sato A. Prediction of Skin Coloration of Grape Berries from Air Temperature. *Hortic. J.* **2018**, *87*, 18–25.
39. Ministry of Agriculture, Forestry and Fisheries. 2021 Global Warming Impact Assessment Report. 2022. Available online: https://www.maff.go.jp/j/seisan/kankyo/ondanka/attach/pdf/report-54.pdf (accessed on 13 February 2023).
40. Yamanashi Prefecture. Yamanashi Prefecture Fruit Tree Agriculture Promotion Plan. 2021. Available online: https://www.pref.yamanashi.jp/documents/1958/r3kasin.pdf (accessed on 13 February 2023).
41. Ministry of the Environment Government of Japan. A-PLAT. Retrieved from Climate Change Adaptation platform. Available online: https://adaptation-platform.nies.go.jp/map/Yamanashi/index_past.html (accessed on 13 February 2023).
42. Yamanashi Prefecture. Grape Farmers Confronting Global Warming. Available online: https://www.pref.yamanashi.jp/oishii-mirai/contents/sustainable/koike_noen.html (accessed on 13 February 2023).
43. Bio-oriented Technology Research Advancement Institution. Early Development of New Grape Varieties that Take Advantage of Local Resources and Respond to Climate Change and Climate Change Impact Assessment. Available online: https://www.naro.go.jp/laboratory/brain/contents/follow_up/pickup/140996.html (accessed on 13 February 2023).
44. Rogiers SY, Greer DH, Liu Y, Baby T, Xiao Z. Impact of climate change on grape berry ripening: An assessment of adaptation strategies for the Australian vineyard. *Front. Plant Sci.* **2022**, *13*, 1094633.
45. NHK WORLD. Japanese Wine Region Goes Organic. Available online: https://www3.nhk.or.jp/nhkworld/en/news/backstories/2088/ (accessed on 13 February 2023).
46. Londhe AA, Patil SR, Mulla IA, Sargar DS, Deshmane PR. IoT Based Smart Agriculture System for Grapes. *Int. J. Adv. Res. Electr. Electron. Instr. Eng.* **2020**, *9*, 33.
47. GSMA. Improving the Yield and Quality of Grape Production in China with IoT, 2020. Available online: https://www.gsma.com/iot/wp-content/uploads/2020/01/IoT-Grapes-report-final-for-web.pdf (accessed on 30 December 2023).
48. Tardaguila J, Stoll M, Gutiérrez S, Proffitt T, Diago MP. Smart applications and digital technologies in viticulture: A review. *Smart Agric. Technol.* **2021**, *1*, 100005.
49. Theron H, Hunted JJ. Mitigation and Adaptation Practices to the Impact of Climate Change on Wine Grape Production, with Special Reference to the South African Context. *S. Afr. J. Enol. Vitic.* **2022**, *43*, 10–25.