# Japan Initiatives of Climate Change Adaptation for Paddy Rice Commodity

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## Abstract

As one of the most consumed staple crops, rice is susceptible to climate change, emphasizing the crucial need to promote the climate adaptation of rice to ensure sustainable food security. This research aims to study the climate change impact and mitigation measures in rice commodity from Japan's perspective to serve as reference for other rice-producing countries. A study case is conducted in Hyogo Prefecture, Japan. Combining literature study and interviews, this study found increasing temperature and unstable rainfall as the most impacting climate change factors to rice commodity. These factors cause decreased yield and quality in the study case area. To mitigate the impacts, several countermeasures have been implemented in Japan *e.g.* water management, cultivation schedule adjustment, fertilizer management, and introduction of heat-resistant cultivar. Both the literature and the interviewees agreed that while introduction of heat-resistant cultivar is the most efficient measure, it bears the highest cost, resources, and time. All in all, climate change impacts in general and vulnerability of paddy rice commodity to the impacts are relatively well observed in Japan as shown from the established tracking system and database. The mitigation measures are done in top-down approach and supported by a bottom-up manner with an organized distribution of responsibilities among the stakeholders.

## Introduction

Staple crop production is one of the most important sectors for society, which has been impacted by climate change recently. In Japan, rice is a major staple crop with an averaged production of 8.11 million tons per year from 2011 to 2020 (Klein, 2022). However, due to the increasing air temperature and abnormal rainfall caused by climate change, rice production in Japan is facing some challenges and multiple countermeasures have been implemented. This research reports the ongoing strategies against climate change in Japan, which may serve as a reference for other countries or regions that face the equivalent issue.

The evidence of climate change in Japan has been reported in the Climate Change Impact Assessment Report published by The Japanese Minister of the Environment. The annual average air temperature has increased by 1.24°C in the last century since 1898, a rate faster than the global average rate (0.74°C per century) (**Figure 1a**). The annual days with high temperature have significantly increased, while the annual days with low temperature have decreased. On the other hand, the days with heavy rainfall (>50 mm per hour) have also increased nationwide (**Figure 1b**). The warming temperature and increasing heavy rain events has caused an increase in natural disasters, heat-related illness and agricultural loss.

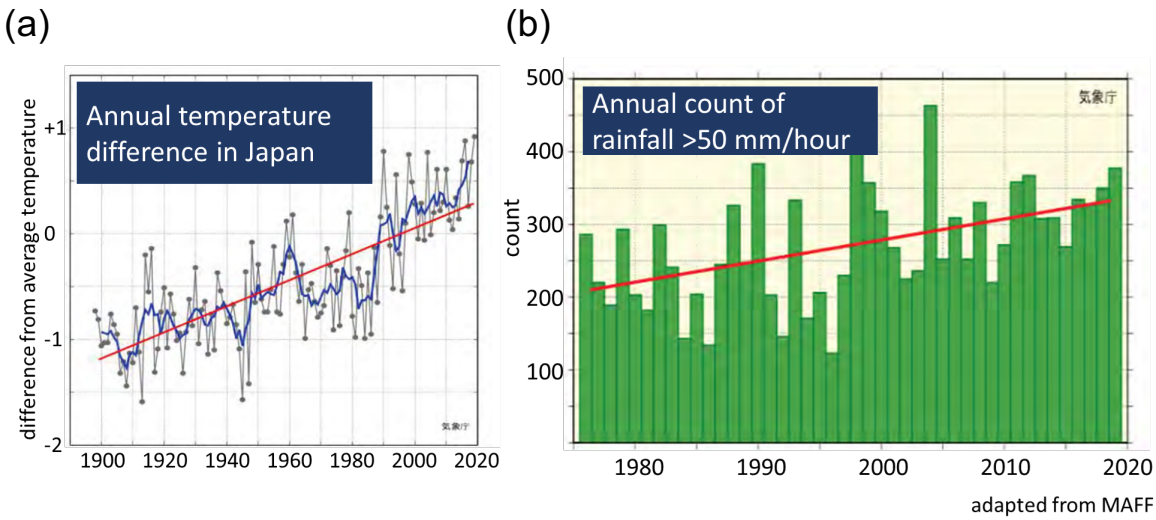


**Figure 1.** Increasing trend of **(a)** annual temperature and **(b)** rainfall count in Japan.

Multiple international and national policies against climate change have been published. The Paris Agreement which came into force on November 2016 calls for countries' united effort to hold the increase of global average temperature to below 2°C or best to 1.5°C above pre-industrial levels by the end of this century. The commitment takes form as the Nationally Determined Contributions (NDCs) submitted by participating countries to communicate their targets and actions they will take to achieve the goal. Japan's NDCs declared target of emission reduction by 46% by FY 2030 compared to FY 2013 and ultimately reaching net-zero by 2050.

As one of Japan's efforts to meet its emission reduction goal and adapt to the climate change impacts, Japan passed the Climate Change Adaptation Act in June 2018. Stipulated on the Act, the Minister of the Environment shall make and publicize a comprehensive assessment of climate change impacts.

The first Japan's climate change impact assessment published on 2020 has pushed forward the progress in studies and collaborations related to climate change assessments and adaptation. For example, the SI-CAT datasets showed projections of future climate conditions with scenarios of global average temperature increase at 4°C and 2°C above pre-industrial levels. The climate projections enabled assessments of future extreme events such as tropical cyclones and heavy rainfall events. Furthermore, in the prefectural and municipal scales, climate change impact assessments and formulation of adaptation strategies have been enabled by the establishment of Climate Change Regional Adaptation Consortium Program. Adaptation actions from various stakeholders including the central government, local governments, the private sector and individuals are promoted through The Climate Change Adaptation Information Platform (A-PLAT) and the Data Integration and Analysis System (DIAS) (Ministry of the Environment, 2020).

Although various policies were found from the above publications, these documents rarely described on-site implementation of the countermeasures to climate change and the role of local communities regarding the implementation. As a result, this research conducted an interview to understand the on-site climate change adaptation measures for paddy rice commodity. The interview was conducted at Hyogo Prefectural Technology Center for Agriculture, Forestry and Fisheries (兵庫県立農林水産技術総合センター), because the high temperature in Hyogo has decreased the rice quality and the institute has been cooperating with local rice farmers and Japan Agricultural Cooperatives to develop strategies against climate change.

## Methods

This study was conducted by a combination of literature survey, visiting the Sake Rice Experimental Station (酒米試験地) and interviewing the researchers of Hyogo Prefectural Technology Center for Agriculture, Forestry and Fisheries (兵庫県立農林水産技術総合センター). Literature survey over governmental documents, press releases, and prior research provided some fundamental knowledge to conduct the study. The demonstrations at the Sake Rice Experimental Station showed the development of heat-resistant rice cultivars and the methods put in use to assess the impact of heat on rice grains. The on-site adaptation implementation and the situation in the local community were understood by the interview.

The interview question sheet was structured by the theoretical framework (**Figure 2**) that was proposed by (Preston et al., 2009). The framework was initially published as a component of the Climate Adaptation Research Flagship of the Australian Commonwealth Scientific and Industrial Research Organisation (CSIRO). It stated that, (1) what are we adapting to, (2) who adapts, (3) how do we adapt, and (4) what do we want to achieve are the four sets of determinants that drive the process of adaptation.

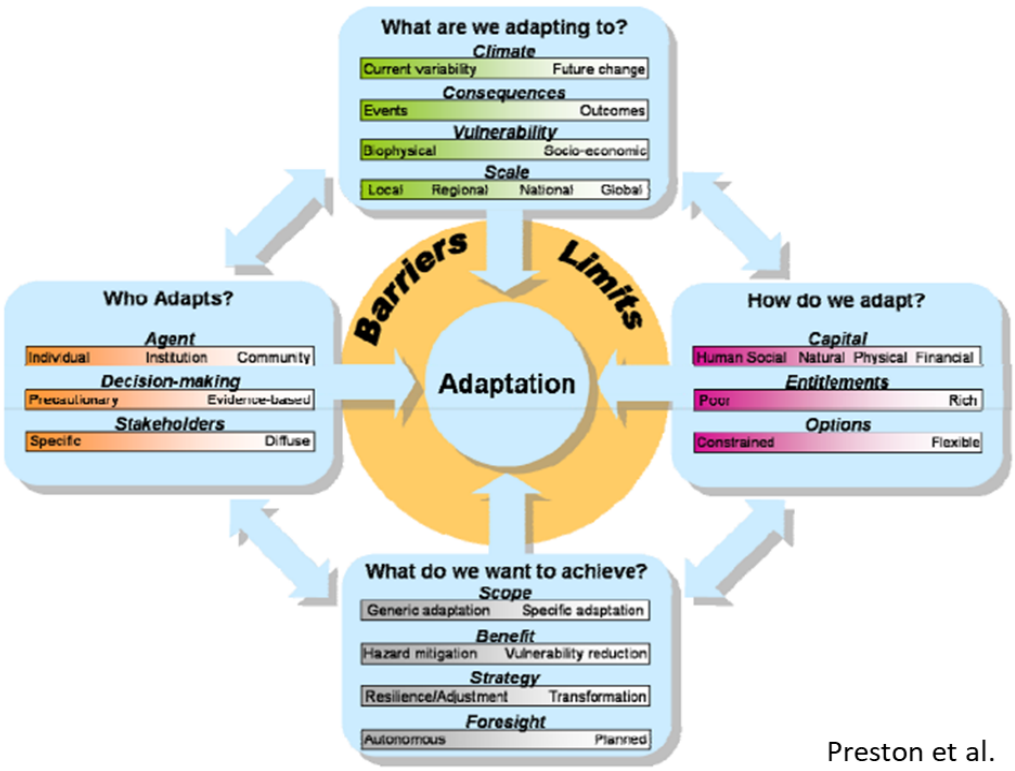


**Figure 2.** Framework for interview questions

According to the research framework, the interview questions was consisted of four parts:
(1) What are we adapting to?

In general, adaptation is needed only when some potential threat exists. In this part, the potential threats of climate change on rice production was identified. The threat was discussed from the social aspect as well as from the biophysical aspect. Furthermore, since different people may have different perceptions of the potential threat, the researchers' and the local farmers' opinion on the topic was asked.

(2) Who adapts?

The key actors and their roles in climate change adaptation were identified in this part. Especially, the collaboration between government, farmers and researchers was hoped to be understood. The command-chain and the funding source was asked to understand the role in charge of the adaptation measures.

(3) How do we adapt to climate change?

The current and potential adaptation measures were discussed in this part. Since the interviewees were agricultural researchers, most of the interest was put on the process to implement researching solutions to practical application. The potential technical solutions and the difficulties to implement them were asked.

(4) What do we want to achieve?

The goal of the adaptation measures was asked in this part. Since objective criteria is required, the assessment method for the effectiveness of the adaptation measures. The key indices, temporal scale and geographical scale of the assessment was asked.

## Literature Review

### *Paddy Rice Climate Impact Assessment*

Global warming has impacted Japan's agriculture, forestry, and fisheries by decreasing yield and deteriorating quality. A change of of agricultural landscape is also expected as plantation is moving to the northern part of Japan in Hokkaido from sub-Tohoku region or sub-Kanto region. The fishing industry is doomed to scarcity due to increased water temperature. Livestock production is also expected to show a decrease in western Japan (Research and Development in Agriculture, 2007). Overall, within the agriculture, forest/forestry, and fisheries sectors, paddy rice fields demonstrated the highest degree of significance, urgency, and confidence (Ministry of the Environment, 2020).

The projected impacts of climate change on rice paddy fields notably affect the yields. For example, in 2010 and 2019 the high temperature in the summer caused the increase of white immature grains and thus reduced the percentage of first-class rice (**Figure 3**) (Ministry of the Environment, 2020). The reduction of first-class rice caused the loss of the rice farmers. A study by (Masutomi et al., 2019) further mentioned that global warming will double the occurrence of chalky rice grain, a phenomenon of decreased rice quality, by 2040 under RCP 8.5 to a scale of one third of paddy rice fields in Japan. This decrease of grain grade is estimated to be equal to an annual economic loss of 401.4 million US$/year.

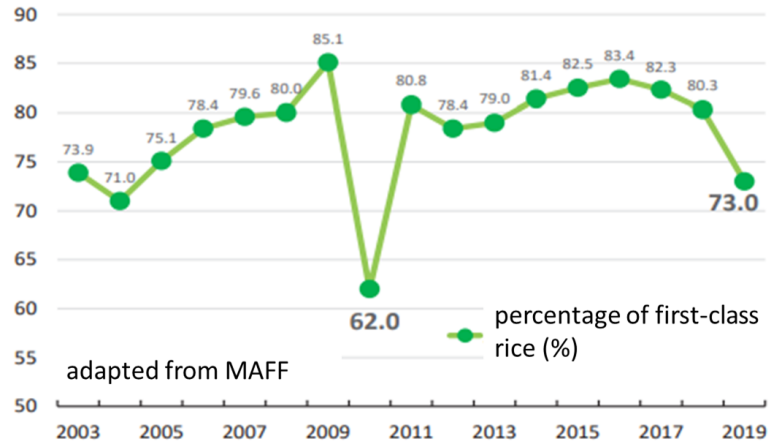


**Figure 3.** Reduction of first-class rice in 2010 and 2019 due to high temperature

Climate change is anticipated to lead to insufficient agricultural water in certain regions,

affecting water, land, and agricultural infrastructure. This is attributed to reduced snowmelt runoff in the wet-ploughing (shirokaki) season for paddy rice cultivation and an elevated threat of harm to low-lying paddy fields due to intensified heavy rainfall (Ministry of the Environment, 2020).

Moreover, some farmers have reported the incidence of white immature grain (**Figure 4**) caused by high temperature. High temperatures during ripening stage increase the occurrences of white immature grains, immature thin grains, and cracked grains. White immature grain has insufficient accumulation of starch causing the white and obscure appearance. These damages lowered the rice grade and price (Watanabe, 2015).

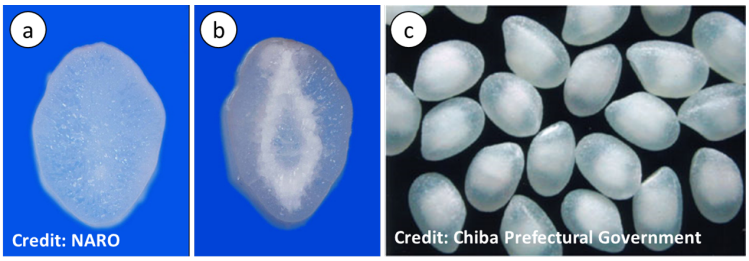


**Figure 4.** Normal grain and white immature grains
(a) sliced normal grain (b) sliced white immature grain (c) white immature grain

In 2021, 17 out of 23 prefectures (74 %) in West Japan reported white immature grain. Among the other 7 categories of harmful effects, high temperature is related to 6 of them. The high temperature is estimated to impact the yields in most areas in West Japan. Accordingly, these areas are projected to face a decrease of yields by 2041 ~ 2060 (**Figure 5)**.

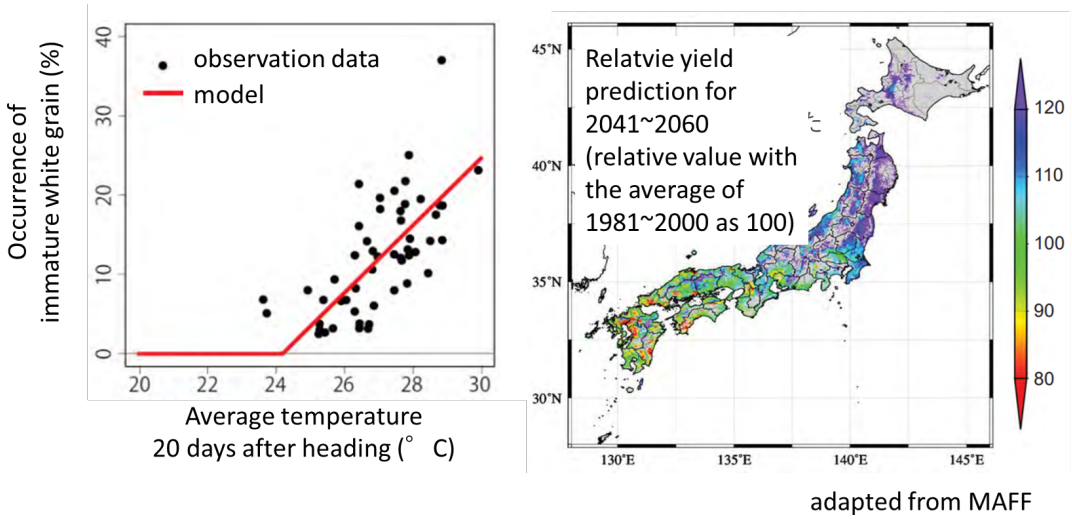


**Figure 5.** Impact of high temperature on agricultural yield

***Climate Impact Countermeasures in Rice Paddy Commodity***

Several countermeasures have been implemented to prevent harm from high temperatures. Among them, water management is the most common method, followed by optimizing the transplant-ripening season, management of fertilizer and introducing new cultivars (**Figure 6**).

| 主な目的 | 実施している適応策（実証中、研究開発中の適応策を含む） | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 水管理の徹底 | 適期移植収穫 | 晩期栽培の徹底（遅植え、移植時期繰り下げ） | 土づくりの徹底 | 肥培管理の徹底 | 追肥 | 籾数制御の徹底 | 夜間かんがい | 害虫防除の徹底 | 土壌還元化対策の徹底 | 品種変更・新品種導入 |
| 白未熟粒の抑制 | 22 | 8 | 4 | 2 | 8 | 5 | 1 | 2 | | | 7 |
| 胴割米の抑制 | 9 | 4 | | | | 1 | | 1 | | | 1 |
| 登熟期の高温遭遇回避 | | 1 | | | | | | | | | |
| 充実不足粒の抑制 | 1 | | | 1 | 1 | | | | | | 1 |
| 着色粒対策（カメムシ対策） | | | | | | | | | 1 | | |
| 品質・収量向上 | 1 | | | 1 | 2 | | | | | 1 | 7 |
| スクミリンゴガイ対策 | | | | | | | | | 1 | | |

harms caused by high temperature

irrigation

planting season

fertilizing

new cultivar

**Figure 6**. Categorization of countermeasures implemented in Kyoto, Osaka, and Hyogo and their objectives. The numbers show the number of countermeasure types which fall into categories. The chart data was taken from the original report in Japanese, followed with English translation in the bottom chart. (Reference: 令和 3 年地球温暖化影響調査レポート)

Irrigation (marked in blue circle in **Figure 6**) is the key to maintain stable rice productivity, since it is required to fill the rice paddies with water until the rice is fully grown to a certain stage. Moreover, research from Ibaraki University also shows that, while the introduction of a new cultivar is the most effective countermeasure, it is also the costliest one of all (**Figure 7**). Japan has put its effort to develop heat resistant cultivars, such as the Nikomaru variety which is said to be recommended due to its good appearance and low occurrence of immature kernels. Although paddy fields receive damage from climate change, it is also one of methane (a global warming gas) contributor, therefore its reduction is also important for example through midseason drainage and alternate wetting and drying irrigation (Research and Development in Agriculture, 2007).

| No. | Adaptive strategy | Time | Cost | Effectiveness | Who takes the initiative? | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | Farmers | Country/ Administration | Researchers | JA etc. | Company |
| 1 | Sophistication/Change of cultivation management | Short | Low | Low-Medium | ✓ | | | | |
| 2 | Variety change (to an existing variety) | Short-Medium | Low | Low-Medium | ✓ | (✓) | | (✓) | |
| 3 | Changing the date of transplant | Short-Medium | Low | Low-Medium | ✓ | (✓) | | (✓) | |
| 4 | Introducing IT (Utilization of satellite data and weather forecasts) | Medium | Medium | Medium | ✓ | | ✓ | | ✓ |
| 5 | Climate and pesticide insurance | Medium | Medium | Medium | ✓ | ✓ | | ✓ | ✓ |
| 6 | Development and introduction of new varieties | Long | High | High | ✓ | ✓ | ✓ | (✓) | ✓ |

**Figure 7.** Organizing the adaptation measures by time, cost, and effectiveness. Data is taken from the original report in Japanese and translated to English. The checkmark with the parentheses indicate that the respective parties are only partly involved in taking the initiatives.
(Reference: 農業生産における気候変動適応ガイド水稲編)

## Results and Discussion

### Climate Change Impact on Paddy Rice Commodity in Hyogo

In this section, the results obtained from the interview will be discussed. The same findings as the literature review on major aspects of climate change in Japan were also mentioned by the researchers in the Hyogo Prefectural Technology Center for Agriculture, Forestry and Fisheries - the most impacting climate change factors for paddy rice commodities are temperature and unstable rainfall.
*"In Japan, agricultural strategies against climate change are mainly decided at the prefectural level. The temperature in Hyogo is measured in 10 different places every 1 hour (open access temperature data is available on the website below*
*https://www.google.com/url?q=https://www.data.jma.go.jp/obd/stats/etrn/view/annually_a.php?prec_no%3D63%26block_no%3D0956%26year%3D1983%26month%3D%26day%3D%26view%3Da1&sa=D&source=docs&ust=1687942688838850&usg=AOvVaw1u8S5vAAEGR-d3nqj01Q-Y).*
*For rice cultivation, temperature is one of the most important factors. However, since the 1980s, the temperature in August has risen by 1.5 degrees; in September by 2 degrees. Other than temperature, typhoons, and unstable rainfall are also major threats. Unstable rainfall makes irrigation difficult."*

Increased temperature and unstable rainfall has caused the paddy rice yield to decline, an impact at a level which the farmers could recognize. However, the specific causal relationship between climate change and the yield decrease is not a common awareness among farmers.
*"The main aftermath of climate change is the income of the farmers. The farmers may not know in detail how temperature would affect the rice quality, but they do have a rough understanding that in some years the rice quality has dropped due to high temperature."*

*Another study based on a nationwide survey and meteorological data (The Agro-Meteorological Grid Square Data, NARO) reported that over half of the farmers implement adaptation measures voluntarily. However, challenges include a limited number of farmers adopting multiple measures and some facing obstacles like high implementation costs or uncertainty about suitable measures. The quantitative analysis reveals that factors like risk and time preferences, age, operational scale, and perceived negative impacts of climate change influence the number of adaptation measures implemented. Interestingly, regions with higher average temperatures tend to implement more adaptation measures. The findings suggest that, along with information dissemination, reducing initial costs and addressing risks can enhance future adoption of adaptation measures by farmers (岡村 & 剛, 2022).*

Regarding the decrease in the rice quality, aligned to the literature finding, the researchers also mentioned the incidence of the white immature grain. The rice disk cuts the rice grains in half when the rice grains are put inside each of the holes (**Figure 8**). White spots were observed instead of a clear translucent appearance.

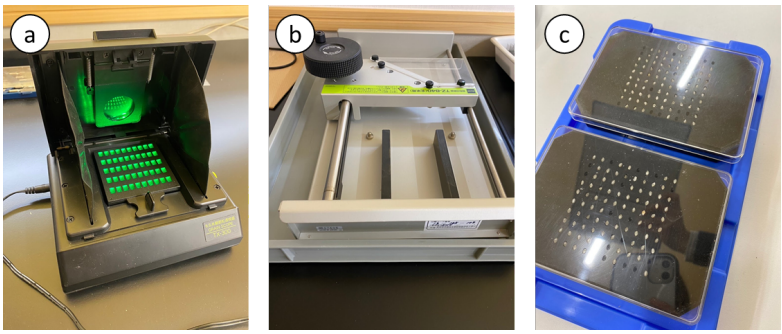

**Figure 8.** Apparatus to identify white immature and broken grains

The interviewee mentioned that education regarding climate change mitigation is still insufficient. According to Khan et al., (2022), the degree of adaptability is closely related to farmers'

education, access to financing services, and knowledge of the climate. Age, primary occupation, income, land ownership, access to irrigation, credit, climatic information, and farm advisory appeared to be the significant predictors of farmers' adaptation decisions, according to the logit model.
*"The education of strategies against climate change to farmers is still not enough. The education is mainly given by the on-site instructors from the education centers and the Japan Agricultural Cooperatives (JA). In Hyogo, there are 13 education centers with about 5 instructors that specialize in rice farming in each center."*

In response to the decreasing yield which affects farmer's income, there is not any financial support specifically addressed for climate change-related impacts although there is mandatory agricultural insurance for disaster-related incidents.
*"No financial support would be given to the farmer when the rice quality decreases. However, there is mandatory agricultural insurance that would provide financial aid when the yield is lower than 20% of the yearly average, which may be caused by typhoons or other disasters."*

Based on the information on the NOSAI (Japan agriculture insurance system), specifically the Prefectural NOSAI of Kumamoto and Shizuoka prefecture, the efforts in identifying and compensating for certain rice grain abnormalities, such as milky-white grains, has been deployed. While rice insurance compensates for yield losses, it typically does not cover quality or grade reductions. However, if widespread occurrences of abnormalities leading to the production of non-standard rice, are confirmed, there is a possibility of special compensation measures being implemented after the union's application and national approval. Farmers are advised to inspect their rice fields, report damages before harvest if high-temperature issues like abnormal ripening are anticipated and understand that even if a claim for damages like milky-white grains is made, special measures may not always be implemented in the future. Additionally, if special measures are implemented, it does not guarantee automatic eligibility for regular insurance compensation; this depends on the subsequent growth and damage assessment (NOSAI Shizuoka and NOSAI Kumamoto, 2023).

**Paddy Rice Climate Impact Countermeasures in Hyogo**

Countermeasures currently implemented in Kato City and Kasai City, Hyogo Prefecture, include adjustment of rice cultivation dates and climate change-resistant varieties, among other measures depending on the regions. Scientific research currently being conducted as climate change mitigations includes five topics listed below.

1. New strain development
2. Fertilizer
3. Pest-that-increased-high-temp control
4. Sowing period (time when they plant the seeds)
5. Cultivation method

*"Concerning climate change the following technologies are being developed, that are adjustment of rice cultivation dates, climate-smart varieties are under development, and in some regions better management of fertilizer is being used."*

Aligned with the literature findings, the interviewee said that while introductions of a new cultivar is the most effective countermeasure, it is also the costliest one.
*"The strategies against climate change is still insufficient. Until now, Hyogo has performed many technical approaches (irrigation, fertilizer, etc.). Of course, by performing these approaches, the result would become somehow better. However, the ultimate solution would be to create new cultivars that adapt to the new climate. The main problem for creating a new cultivar is that it takes a lot of effort. Usually, it takes about 10 years to create a new cultivar."*

From the interview, Japan seems to have a relatively systematic, top-down approach to coordinating the countermeasures. The prefecture has its own independence in deciding the countermeasures based on the statistical data.
*"The administrative staff of the prefectural government could identify problems by the statistical data*

*(e.g. the percentage of first-grade rice of a certain cultivar). They would decide how the governmental funds could be used to solve the problem (e.g. taking technical approaches, investing in research, etc.). If it is decided to be solved by research, the research team would propose some strategies. The process does not involve the national level."*
It was also noted that although Japanese government provides general support to citizens in case of typhoons and other disasters, there will be no direct financial aid to the farmers whose revenues have declined due to climate change.

In deciding climate change countermeasures, several key stakeholders are involved *i.e.* administrative staff, JA, private companies, and farmers. The administrative staff acts as the main decision-maker.
*"Research concerning climate change is managed by the organization. Multiple levels of management meetings occur. Multiple departments are involved in the research development. For example, to promote a new cultivar, seed producers' cooperation is needed. JA decides the strategy to sell and introduce the new cultivar. Administrative staffs control the project. For a new technology to be used practically, it has to pass the so-called Darwinian sea."*
Darwinian sea was mentioned as a term showing difficulties in the process of social implementation of technology, especially in receiving recognition by customers in the market and gaining acceptance without being removed from the market.
*"The research fund mainly comes from Prefectural government and the JAs (about 14 JAs exist in Hyogo). Private companies also ask for support from the research institute. For example, to develop a software to determine the harvesting season, lots of research data would be needed. Also, sake breweries would ask research institutes to evaluate the sake/rice."*
*"The administrative department and JA decide what strategy to implement."*

We also found from the interview that international stakeholder collaboration is also conducted on a national level, though not at the prefectural level.
*"At the prefectural level, international collaboration does not exist, but it does exist at the national level. For example, a collaboration between the Philippines for climate change strategy bred IR64, a successfully developed strain with high quality and resistance to heat and harmful insects."*
*The Indian variety IR64 was bred at the International Rice Research Institute (IRRI) with collaboration of Japan, now widely used in tropical regions.*

In conducting the climate change countermeasures, the administrative staff and JA also act as the key stakeholders. The interviewee mentioned about the challenges in implementing the countermeasures *e.g.* translating the research.
*"Administrative staff and JA control the project for climate change."*
*"Farmers would not receive any financial aid when they implement a new strategy, so mutual trust is of great importance. Some certificates would be presented to the farmers to prove how the new strategy could help increase the quality."*

In order to a new cultivar as a climate change countermeasure, successful implementation cooperation between various stakeholders is required.
*"When they get a successful strain, they will test it in several farms before applying it to spread it. The administrative representative has the right to make decisions."*
*"They need cooperation between seed producers, fertilizer producers, farmers, JA, and prefectural administration. The farmers have multiple kinds of organizations for example as a company, family corporations, and villages."*
*"They wanted to test the optimal cultivation condition and it took 3 years. Implementing the results to the farm took another 3 years."*

The interviewee had also mentioned that the effects of mitigation implementations were assessed every 3 years, according to certain key performance indicators.
*"They measure the impact by using a certain Key Performance Indicator and send it to the Prefectural Administrative. The assessment is done every 3 years."*

As the regions have a long experience in rice heat-resistant cultivar research and development, they mentioned a challenge in conducting the research and in the implementation.

*"Controlling the temperature is the most difficult challenge. For example, 24 °C is the most suitable temperature for rice cultivation (eating rice) while 27 °C or above will reduce the quality. Since the temperature range is narrow, they developed a temperature control machine to adjust it. The research is conducted in real-time temperature, as the temperature trend is not linear, during the low temp years they could not conduct the research."*

*"Difficult to implement routine change and some aspects such as brand cannot be easily changed for example Koshihikari"*

We caught a glimpse of the difficulty of scientific research as a climate change mitigation measure, setting up detailed experimental conditions, while dealing with the annual climate changes in the region.

## Conclusion

To better respond the climate change impact in Japan, Japanese government has formulated the legal framework to deal with the climate change impacts, initiated with the "Report on Assessment of Impacts of Climate Change in Japan and Future Challenges" in March 2015. Accordingly, the Assessment Report on Climate Change Impacts in Japan published in December 2020 presented the climate change observation and projections in Japan, with some notable impacts including increased average air temperature with increased temperature fluctuations, increased heavy rainfall, frequency of rainfall, and number of dry days per year. These trends pose detrimental effects on paddy rice commodity *i.e.* decreased yield, increased risk of damage, and decreased quality. These impacts were also observed in the study case area, Hyogo Prefecture, Japan, in which temperature increase and unstable rainfall being the most damaging factors to paddy rice commodity. Due to these factors, the rice yield and commodity were impacted, for example white immature grains as one phenomenon that showed paddy rice quality decrease was well-observed.

To mitigate the impacts, several countermeasures have been implemented *e.g.* water management, transplant-ripening season, management of fertilizer, and introducing new cultivars. In the Hyogo Prefecture, the implemented mitigation measures include new strain development, adjusting fertilizer application, pest-that-increased-high-temp control, sowing period (time when they plant the seeds) modification, and cultivation method adjustment. Agreeing with the literature, while introduction of new cultivar is the most effective countermeasure, it also bears the highest cost, resources, and time.

Overall, climate change impacts in general and vulnerability of paddy rice commodity to the impacts are relatively well observed in Japan as shown from the established system and database. The mitigation measures are done in a top-down and bottom-up manner with an organized distribution of responsibilities among the stakeholders. Therefore, hearing the farmers' perspectives would support the top-down perspective reported in this study.

## Future Study

From the current findings from literatures, the research might be expanded, however not limited to investigate the perspectives of the farmers regarding the initiatives and implementation of the climate change countermeasures. Moreover, to do a comparative study of the impacts and measures taken from other Asian countries relevant to paddy rice commodity.

## Acknowledgement

This study was supported by the Experienced-Based Learning scheme of Asian Future Leaders Scholarship Program in Kyoto University (Bai Xian Asia Institute). We gratefully acknowledge the participation of the researchers at the Sake Rice Experimental Station (酒米試験地) and Hyogo Prefectural Technology Center for Agriculture, Forestry and Fisheries (兵庫県立農林水産技術総合センター). We thank Yoshitaka Iwasaki (岩﨑吉隆) for providing useful comments on the manuscript.

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