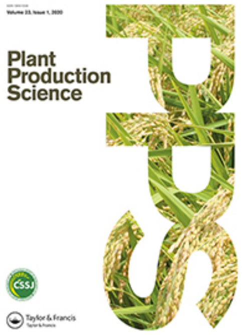


Plant Production Science

ISSN: 1343-943X (Print) 1349-1008 (Online) Journal homepage: https://www.tandfonline.com/loi/tpps20

Yield response of high-yielding rice cultivar Oonari to different environmental conditions

Yumiko Arai-Sanoh, Masaki Okamura, Jun Hosoi, Kenji Nagata, Toshiyuki Takai, Hitoshi Ogiwara, Junko Ishikawa, Hidemitsu Sakai, Takeshi Tokida & Nobuya Kobayashi

To cite this article: Yumiko Arai-Sanoh, Masaki Okamura, Jun Hosoi, Kenji Nagata, Toshiyuki Takai, Hitoshi Ogiwara, Junko Ishikawa, Hidemitsu Sakai, Takeshi Tokida & Nobuya Kobayashi (2020) Yield response of high-yielding rice cultivar Oonari to different environmental conditions, Plant Production Science, 23:1, 69-74, DOI: 10.1080/1343943X.2019.1651207

To link to this article: https://doi.org/10.1080/1343943X.2019.1651207

PLANT PRODUCTION SCIENCE
2020, VOL. 23, NO. 1, 69–74
https://doi.org/10.1080/1343943X.2019.1651207

Taylor & Francis
Taylor & Francis Group

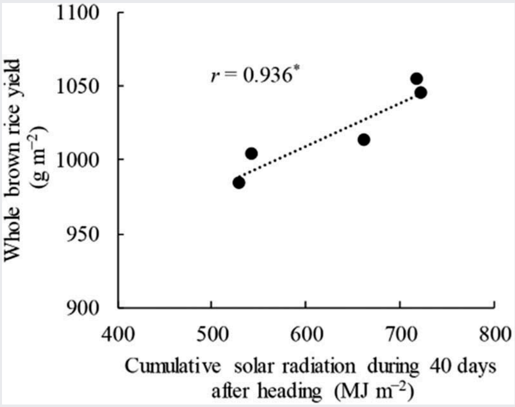
SHORT REPORT

Yield response of high-yielding rice cultivar Oonari to different environmental conditions

Yumiko Arai-Sanoh[a], Masaki Okamura[a,b], Jun Hosoi[c], Kenji Nagata[d], Toshiyuki Takai[a,e], Hitoshi Ogiwara[a], Junko Ishikawa[a], Hidemitsu Sakai[f], Takeshi Tokida[f] and Nobuya Kobayashi[a]

[a]NARO Institute of Crop Science, Tsukuba, Ibaraki, Japan; [b]NARO, Central Region Agricultural Research Center, Joetsu, Niigata, Japan; [c]Nagano Prefecture Agricultural Experiment station, Suzaka, Nagano, Japan; [d]NARO Western Region Agricultural Research Center, Fukuyama, Hiroshima, Japan; [e]Japan International Research Center for Agricultural Sciences, Tsukuba, Ibaraki, Japan; [f]NARO Institute for Agro-Environmental Sciences, Tsukuba, Ibaraki, Japan

ABSTRACT
A new rice (*Oryza sativa* L.) cultivar, ‘Oonari’, was developed to reduce the shattering habit of the high-yielding cultivar ‘Takanari’. To evaluate the effects of environment on its yield and related traits, Oonari and Takanari were grown in multiple environmental conditions at three locations in Japan. The whole and filled brown rice yields of Oonari were around 1000 g m^{-2}, similar to those of Takanari. But the panicle number m^{-2} of Oonari was slightly but significantly higher than that of Takanari and the spikelet number per panicle was slightly but significantly lower. With respect to the effect of environment on yield of Oonari, cumulative radiation during 40 days after heading was positively related to whole brown rice yield of Oonari. Yield tended to be higher under increased atmospheric CO$_2$ concentration than under ambient. Oonari was confirmed to exhibit high yield in various environmental conditions.



ARTICLE HISTORY
Received 17 August 2018
Revised 10 July 2019
Accepted 22 July 2019

KEYWORDS
CO$_2$; climate change; FACE; Oonari; rice (*Oryza sativa* L.); weather condition; yield

Introduction

Rice (*Oryza sativa* L.) is an important crop and a major source of food for more than a third of the world’s population (Khush, 1997). A continuous increase in rice production is required to meet the demands of increasing population (Tilman et al., 2011).

‘Takanari’ is one of the highest-yielding rice cultivars in Japan. The whole brown rice yield of Takanari is as high as about 1000 g m^{-2} in Japan (Yoshinaga et al., 2013). However, Takanari, derived from a cross between *indica*- and *japonica*-type parents, is prone to seed shattering (Ando, 1990), which can lead to yield losses during harvesting. To reduce the shattering habit of Takanari, a new cultivar, ‘Oonari’ was developed by γ-irradiation of Takanari at the National Agriculture and Food Research Organization (NARO) of Japan and released in 2015 (Kobayashi et al., 2016). The whole brown rice yield of Oonari was higher than that of Takanari (Kobayashi et al., 2016), but the yield traits have not yet been clarified. It is important to reveal yield response of new high-yielding rice cultivars to various environmental conditions.

Crop growth and yield are affected by various environmental conditions (Horie et al., 1995; Peng

CONTACT Nobuya Kobayashi nobuya@affrc.go.jp
Supplemental Materials data for this article can be accessed here.

et al., 2004; Porter et al., 2014; Yoshida & Parao, 1976). Among these, air temperature and solar radiation are the major environmental factors that determine crop yield. In addition, carbon dioxide concentration ([CO_2]) is a notable factor in light of the continuing global increase: atmospheric [CO_2] has risen from 280 μmol mol^{-1} before the Industrial Revolution to 409 μmol mol^{-1} in 2018 (Earth Systems Research Laboratory, 2018), and is projected to rise further during the next 50 years even if efforts are made to reduce emissions (Fisher et al., 2007). Yield responses to these conditions show varietal differences (Hasegawa et al., 2013; Nagata et al., 2016; Nakano et al., 2017; Shimono et al., 2009). However, the responsiveness of the yield-related traits of Oonari to environment has not yet been clarified.

Therefore, in this study, we compared brown rice yield and yield components between Oonari and Takanari at three distant locations in Japan: Tsukuba (eastern lowlands, 12 m above sea level) where these cultivars were developed, Fukuyama (western lowlands, 1 m above sea level) and Nagano (central highlands, 340 m above sea level) which is known to be high yielding region for rice in Japan. We investigated the effect of environmental conditions on the yield traits. We also investigated the responses of the yield traits of Oonari to increased atmospheric [CO_2] in a free-air CO_2 enrichment (FACE) facility.

Materials and methods

Plant materials and cultivation

Takanari and Oonari were grown in field experiments in all three locations. Cultivation methods in each location were shown in Table 1. Fertilizers were applied as following practice in each location.

In Tsukuba, we applied a basal dressing of manure at about 1 kg m^{-2} and chemical fertilizers at rates of 16 and 12 g m^{-2} (P_2O_5 and K_2O) in two cultivars and 12 g N m^{-2} (as controlled-release fertilizer: equal parts LP40 and LP100; JCAM Agri, Tokyo, Japan). We applied a topdressing of LP40 at 4 g N m^{-2} at the panicle formation stage. LP40 and LP100 fertilizers release 80% of their total N content at a uniform rate up to 40 and 100 days, respectively, after application, at soil temperature at 25°C.

In Fukuyama, we applied a basal dressing of chemical fertilizers at 12 g N m^{-2} (as controlled-release fertilizer: equal parts LP40 and LP100; JCAM Agri, Tokyo, Japan), rates of 10 g m^{-2} each of P_2O_5 and K_2O. We applied a topdressing of LP40 at 6 g N m^{-2} at the panicle formation stage. In 2014, we applied a basal dressing of 4.0 g m^{-2} (N, P_2O_5 and K_2O each), and topdressings of 2 g m^{-2} (N, P_2O_5 and K_2O each) at tillering, 3 g m^{-2} (N, P_2O_5 and K_2O each) at panicle neck node differentiation and panicle formation, and 3 g N m^{-2} at meiosis stage.

In Nagano, we applied a basal dressing of manure at about 2 kg m^{-2} and a chemical fertilizer at the rate of 7, 9.8 and 11.2 g m^{-2} (N, P_2O_5 and K_2O). We applied topdressings of 3, 4.2 and 4.8 g m^{-2} (N, P_2O_5 and K_2O) at tillering, 7.5 and 3.8 g m^{-2} (N and K_2O) at panicle formation stage, and 4.5 and 2.5 g m^{-2} (N and K_2O) 14 days later.

At maturity, when approximately 85% of grains became yellow, we sampled from each replicate to measure yield and its components in each site. Plants were harvested carefully by hand and packed immediately into nylon net bags to avoid loss by shattering during transport and drying.

FACE experiment

We transplanted Oonari on 24–25 May 2017 in the FACE experimental site as shown in Table 1. We applied a basal dressing of 19 g N m^{-2} (as controlled-release fertilizer: equal parts LP40, LPs100, and LP140; JCAM Agri, Tokyo, Japan as), and 10 g m^{-2} each for P_2O_5 and K_2O. LPs100 fertilizer releases 80% of its total N content

Table 1. Cultivation methods.

Location	Site			Year	Plot area (m^2)	Reprication	Sampled hill no. per rep.
Tsukuba	Experimental paddy field at NARO Institute of Crop Science	Tsukubamirai, Ibaraki	36°02′N, 140°04′E	2013	5.4	6	48
				2017	17.9	4	48
Fukuyama	Experimental paddy field at the NARO Western Region Agricultural Research Center	Fukuyama, Hiroshima	34°29′N, 133°23′E	2013	11.5	3	60
				2014	7.2	3	42
Nagano	Experimental paddy field at the Nagano Agricultural Experiment Station	Suzaka, Nagano	36°39′N, 138°17′E	2017	4.8	2	40
FACE	Farmers' fields	Tsukubamirai, Ibaraki	35°58′N, 139°60′E	2017	6.5	3	20

Planting density at 22.2 hills m^{-2} (15 cm × 30 cm), with one plant per hill in Tsukuba and three plants per hill in the other sites.

at a sigmoidal rate up to100 days after application at soil temperature at 25°C.

Detailed descriptions on the FACE experiment are presented by Nakamura et al. (2012). In brief, the elevated [CO_2] treatments were imposed on octagonal plots ('FACE rings') in the fields. Each 'FACE ring' which was 240 m^2 in area and 17 m in inside diameter, was prepared in combination with a corresponding ambient [CO_2] plot. We used four fields as replications, each with a pair of FACE and ambient control plots with their centers 75 m apart to minimize cross-contamination. From transplanting to harvest, the target [CO_2] was 200 μmol mol^{-1} above ambient, and CO_2 was supplied during daylight hours. The season-long daytime average [CO_2] was 585 ± 1.6 μmol mol^{-1} in the FACE plots and 391 μmol mol^{-1} in the ambient plots.

Weather conditions

The weather conditions during the growing season at each site were shown in Supplementary Figure S1.

Statistical analysis

All statistical analyses were conducted in statistical analysis software R (Core Team, 2017). Yield and components in Tsukuba and Fukuyama were tested by analysis of variance (ANOVA). Pearson's correlation analysis and a test for no correlation in Oonari were conducted using five sets of data obtained from Tsukuba, Fukuyama and Nagano. FACE experiment data were analyzed by paired *t*-test ($p < 0.05$).

Results

1. Yield and its components between Oonari and Takanari at three sites

The whole and filled brown rice yields of Oonari were ranged from 983 to 1053, and from 908 to 1016 g m^{-2}, respectively, in Tsukuba and Fukuyama (Table 2). These brown rice yields of Takanari were ranged from 905 to 1068, and from 884 to 1042 g m^{-2}, respectively. There were no significant differences in whole and filled brown rice yields between Oonari and Takanari in Tsukuba and Fukuyama in each year (Table 2; Supplementary Tables S1 and S2). Among yield components, Oonari had a significantly higher panicle number m^{-2} and a significantly lower spikelet number per panicle than Takanari in Tsukuba and Fukuyama. The grain yield and its components in Nagano showed a similar tendency as in Tsukuba and Fukuyama (Table 2). In Tsukuba, Oonari had more total spikelets m^{-2} than Takanari. Furthermore, Oonari had a significantly lower percentage of filled spikelets, but a significantly higher 1000-grain weight than

Table 2. Grain yield and yield components of Oonari and Takanari in field experiments.

	Year	Cultivar	Whole brown rice yield (g m^{-2})	Filled brown rice yield (g m^{-2})	Panicle no. (m^{-2})	Spikelet no. ($panicle^{-1}$)	Total spikelets (×103 m^{-2})	Filled spikelets (%)	1000-grain wt. (g)
Tsukuba	2013	Oonari	1053	1016	321	208	66.6	72.2	21.1
		Takanari	1068	1042	289	220	63.3	79.0	20.8
	2017	Oonari	983	951	315	177	55.8	78.4	21.8
		Takanari	905	884	283	190	53.7	76.6	21.5
Fukuyama	2013	Oonari	1044	962	394	142	55.9	80.5	21.4
		Takanari	1049	990	371	148	54.8	84.6	21.4
	2014	Oonari	1003	908	368	170	62.6	66.1	22.0
		Takanari	1009	922	326	190	61.7	68.3	21.9
Nagano	2017	Oonari	1013	996	288	183	52.6	86.6	21.9
		Takanari	984	961	278	201	55.8	81.3	21.3

Grains thicker than 1.6 mm in Tsukuba and Nagano and 1.8 mm in Fukuyama were considered as filled brown rice and were counted to calculate 1000-grain weight. Yield and 1000-grain weight are presented at a water content of 15%. The percentage of filled spikelets was calculated as the number of filled spikelets divided by the total number of spikelets.

Table 3. Weather conditions during the growing periods of Oonari.

					Mean air temperature (°C day^{-1})		Cumulative solar radiation (MJ m^{-2})	
Site	Year	Transplanting date	Heading date	Harvest date	Before heading	40 days after heading	Before heading	40 days after heading
Tsukuba	2013	May 10	Aug 1	Sep 10	22.5	26.8	1488	719
	2017	May 18	Aug 4	Sep 27	23.6	24.6	1476	530
Fukuyama	2013	May 13	Jul 30	Sep 13	24.8	27.8	1535	723
	2014	May 13	Jul 31	Sep 13	23.6	26.1	1471	544
Nagano	2017	May 11	Aug 15	Sep 30	21.9	21.6	2027	663

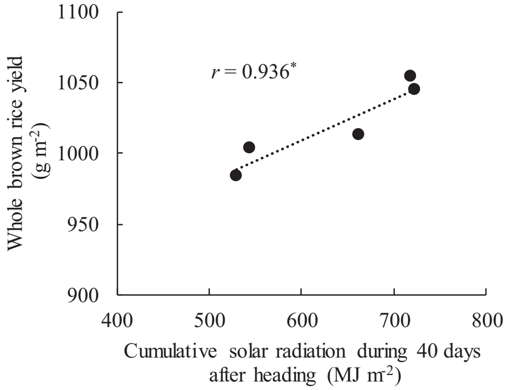


Figure 1. Relationship between cumulative solar radiation during 40 days after heading and whole brown rice yield of Oonari. $^*p < 0.05$.

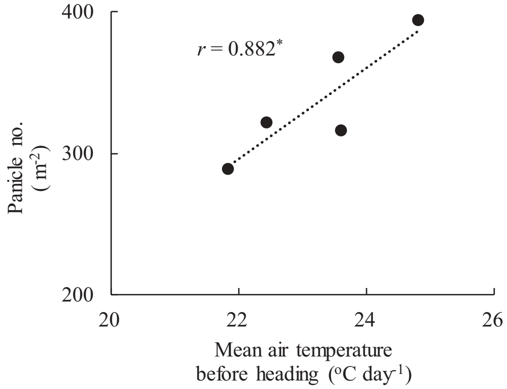


Figure 2. Relationship between mean air temperature before heading and panicle number of Oonari. $^*p< 0.05$.

Takanari. On the other hand, in Fukuyama, there was no significant difference in total spikelet number between cultivars. In addition, Oonari had a significantly lower percentage of filled spikelets than Takanari, but there was no significant difference in 1000-grain weight between cultivars.

2. *Effects of weather on yield and its components among sites of Oonari*

The mean air temperature during the growing periods of Oonari was lower in Nagano than in Tsukuba and Fukuyama (Table 3; Supplementary Figure S1). The solar radiation in June was higher in Nagano than in Tsukuba and Fukuyama, whereas that in August was higher in Tsukuba and Fukuyama in 2013 than in other sites and years (Supplementary Figure S1). The cumulative solar radiation before heading was higher in Nagano than in Tsukuba and Fukuyama, whereas that during the 40 days after heading was highest in Tsukuba and Fukuyama in 2013. There was a significant correlation of whole brown rice yield with cumulative radiation during 40 days after heading, but not with cumulative radiation before heading or with mean air temperature either before heading or during 40 days after heading (Figure1; Supplementary Table S3). Takanari had also the same tendency as Oonari (data not shown).

There was a significant correlation of panicle number with mean air temperature before heading, but not with mean air temperature during 40 days after heading or with cumulative radiation either before heading or during 40 days after heading (Figure 2; Supplementary Table S3). There were no significant correlations with spikelet number either. Takanari also had the same tendency as Oonari (data not shown).

3. *Effects of increased atmospheric [CO_2] on yield and its components of Oonari*

Under increased [CO_2] in FACE, the whole and filled brown rice yields of Oonari were 937 and 900 g m^{-2}, respectively. There were no significant differences in yields or yield components of Oonari (Table 4). However, whole and filled brown rice yields tended to be higher (FACE/ambient = 1.17 and 1.16, respectively) and total spikelet number m^{-2} tended to be larger (FACE/ambient = 1.15) in Oonari under increased [CO_2].

Discussion

We investigated the yield traits of Oonari at three locations in Japan and to clarify the effects of environment on the yield traits of this high-yielding cultivar. We also investigated the responses of the yield traits to increased [CO_2].

Table 4. Grain yield and yield components of Oonari affected by CO_2 concentration in Tsukubamirai in 2017.

CO2 concentration	Whole brown rice yield (g m^{-2})	Filled brown rice yield (g m^{-2})	Panicle no. (m^{-2})	Spikelet no. (panicle^{-1})	Total spikelets (×10^{3}m^{-2})	Filled spikelets (%)	1000-grain wt. (g)
Ambient (A)	803	776	325	158	51.2	67.9	22.3
FACE (F)	937	900	358	164	59.0	69.0	22.1
F/A	1.17	1.16	1.10	1.04	1.15	1.02	0.99
t-test results	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

n.s., not significant.

The yield of Oonari was as high as that of the high-yielding Takanari at all three locations. In a previous report, the whole brown rice yield was higher in Oonari than in Takanari (Kobayashi et al., 2016). Unlike the previous study, we harvested plants using nylon net bags to avoid loss by shattering. We found no significant difference in the whole and filled brown rice yields between Oonari and Takanari (Table 2; Supplementary Tables S1 and S2). We attribute the equally high yield of Oonari to its improved shattering habit. Therefore, we would expect practical yields of Oonari to be higher than those of Takanari when rice is harvested by machine.

Among yield components, the number of panicles m^{-2} was 2–9% larger and the number of spikelets per panicle was 6–9% smaller in Oonari than in Takanari at all three locations (Table 2; Supplementary Tables S1 and S2). Therefore, Oonari differs from Takanari not only in shattering habit but also slightly in these yield-related traits.

Grain yield is determined by the complex sink (total number of spikelets per unit area × filled grain weight) – source (carbohydrate supply to panicle) balance. The improvement of sink production efficiency would result in the increase in the yield potential in the *indica*-dominant varieties (Yoshinaga et al., 2013). However, in this study, under heavy N fertilization (15–19 kg N m^{-2}), total spikelets number was high ($>52.6 \times 10^3$ m^{-2}) at all three locations (Table 2; Supplementary Tables S1 and S2). There was no correlation between the number of total spikelets and whole brown rice yield ($r = 0.41$, Table 2; Supplementary Tables S1 and S2), irrespective of year or location. In addition, cumulative radiation during the 40 days after heading was related to whole brown rice yield of Oonari (Figure 1; Supplementary Table S3). Kobayashi and Nagata (2018) also reported that solar radiation during 20 days after heading had a significant positive correlation with yield of a *japonica*-dominant high-yielding cultivar, Yamadawara. These results may imply that carbohydrate supply to grains after heading, but not spikelet productivity before heading, is the major factor determining brown rice yield of Oonari, which is *indica*-dominant cultivars, under heavy N fertilization.

We presume that yield can be increased further if the ability to supply carbohydrates to grain after heading could be increased, such as through genetic improvement by breeding or the development of field management methods more suitable for Oonari.

Nagano Prefecture is ranked the highest in rice yield per unit area almost every year in Japan (Ministry of Agriculture, Forestry and Fisheries, 2019). Therefore, we expected that the whole brown rice yield of Oonari would be highest in Nagano. Instead, yields were similar at all three locations (Table 2; Supplementary Tables S1 and S2). Among yield components, the number of panicles was smaller, and therefore the number of total spikelets tended to be smaller, in Nagano than in the other regions. There was significant correlation between panicle number and mean air temperature before heading (Figure 2). This may imply that the tiller number was reduced by the low mean air temperature before heading in Nagano, and so the number of panicles at heading was low.

We also investigated the effects of increased [CO_2] on yield traits of Oonari to assess the effects on a high-yielding cultivar, as yield responses to increased [CO_2] have shown varietal differences (Hasegawa et al., 2013; Nakano et al., 2017; Shimono et al., 2009). The grain yield of Takanari, with a large sink capacity, increased more in response to increased [CO_2] than that of Koshihikari, with a smaller sink capacity (Hasegawa et al., 2013). Our results suggest that the yield of Oonari, with an equally large sink capacity, also increased under increased [CO_2] (Table 4). Among yield components, the number of total spikelets m^{-2} tended to be larger, while the percentage of filled spikelets was similar under increased [CO_2]. Thus, the larger sink capacity of Oonari and the improvement of source ability by increased [CO_2] increased the whole brown rice yield, as in Takanari.

The results of our field experiments to clarify the effects of environment on the yield response of Oonari in different locations lead to the conclusion that the grain yield of Oonari can reach around 1000 g m^{-2} in various environments, including under higher [CO_2], similar to that of the high-yielding Takanari, which is already in production. Our results also suggest that carbohydrate supply to grains after heading is an important factor in achieving the higher yield of Oonari. To attain higher and stable grain yields, further study is needed to clarify the physiological mechanisms underlying the source abilities of Oonari.

Acknowledgments

We express our gratitude to the staff of the research support section at NARO and the technical support staff of our laboratories. We thank Hirofumi Nakamura, of Taiyo Keiki, for his support in the FACE experiment.

Disclosure statement

No potential conflict of interest was reported by the authors.

ORCID

Takeshi Tokida http://orcid.org/0000-0001-7245-2952

References

Ando, I. (1990). Suitou "Takanari" no ikusei [Breeding a new rice cultivar 'Takanari']. *Nihon Sakumotsu Gakkai Kantou Shibukaihou*, *5*, 63–64.

Core Team, R. (2017). R: A language and environment for statistical computing. R foundation for statistical computing. Vienna, Austria. Retrieved from https://www.R-project.org/

Earth Systems Research Laboratory. (2018). Global Monitoring Division, National Oceanographic and Atmospheric Administration, US Department of Commerce. Trends in atmospheric carbon dioxide. Retrieved from http://www.esrl.noaa.gov/gmd/ccgg/trends/

Fisher, B. S., Nakicenovic, N., Alfsen, K., Corfee Morlot, J., de la Chesnaye, F., Hourcade, … Warren, R. (2007). Issues related to mitigation in the long-term context. In B. Metz, O. R. Davidson, P. R. Bosch, R. Dave, & L. A. Meyer (Eds.), *Climate change 2007: Mitigation. Contribution of working group III to the fourth assessment report of the intergovernmental panel on climate change* (pp. 169–250). Cambridge: Cambridge University Press.

Hasegawa, T., Sakai, H., Tokida, T., Nakamura, H., Zhu, C., Usui, Y., … Makino, A. (2013). Rice cultivar responses to elevated CO_2 at two free-air CO_2 enrichment (FACE) sites in Japan. *Functional Plant Biology*, *40*, 148–159.

Horie, T., Kropff, M. J., Centeno, H. G., Nakagawa, H., Nakano, J., Kim, H. Y., & Ohnishi, M. (1995). Effect of anticipated change in global environment on rice yields in Japan. In S. Peng, K. T. Ingram, H.-U. Neve, & L. H. Ziska (Eds.), *Climate change and rice* (pp. 291–302). Manila: Springer-Verlag, Berlin and International Rice Research Institute.

Khush, G. S. (1997). Origin, dispersal, cultivation and variation of rice. *Plant Molecular Biology*, *35*, 25–34.

Kobayashi, H., & Nagata, K. (2018). Gyoumu kakouyou suitou hinshu "Yamadawara" no tashu jyouken [Increasing the brown rice yield of palatable cultivar "Yamadawara" to over 800 g m^{-2}]. *Nihon Sakumotsu Gakkai Kiji*, *87*, 67–75.

Kobayashi, N., Ishii, T., Yamaguchi, M., Hirabayashi, H., Takeuchi, Y., Kuroki, M., … Kato, H. (2016). 'Takanari' no datsuryusei wo kaizen shita suitou tashu hinshu 'Oonari' no ikusei [Breeding of rice high-yielding cultivar 'Oonari' by improving shattering habit of 'Takanari']. *Ikushugaku Kenkyu*, *18*(Ex. 1), 143.

Ministry of Agriculture, Forestry and Fisheries. (2019, February 22). Sakumotsu toukei chousa [Statistics of Japan (e-stat)] Retrieved from https://www.e-stat.go.jp/stat-search/file-download?statInfId=000031799397&fileKind=0

Nagata, K., Ohsumi, A., Yoshinaga, S., & Nakano, H. (2016). Suitou tashu hinnshu niokeru toujyukuki kishoujyouken to shuuryou tono kannkei no hinshukansai [Cultivar difference in the yield response to climatic conditions after heading stage in high-yielding rice cultivars]. *Nihon Sakumotsu Gakkai Kiji*, *85*, 367–372.

Nakamura, H., Tokida, T., Yoshimoto, M., Sakai, H., Fukuoka, M., & Hasegawa, T. (2012). Performance of the enlarged Rice-FACE system using pure CO_2 installed in Tsukuba. *Japanese Journal of Agricultural Meteorology*, *68*, 15–23.

Nakano, H., Yoshinaga, S., Takai, T., Arai-Sanoh, Y., Kondo, K., Yamamoto, T., … Kondo, M. (2017). Quantitative trait loci for large sink capacity enhance rice grain: Yield under free-air CO_2 enrichment conditions. *Scientific Reports*, *7*, 1827.

Peng, S., Huang, J., Sheehy, J. E., Laza, R. C., Visperas, R. M., Zhong, X., & Cassman, K. G. (2004). Rice yields decline with higher night temperature from global warming. *Proceeding of National Academy Science. U.S.A.*, *101*, 9971–9975.

Porter, J. R., Xie, L., Challinor, A. J., Cochrane, K., Howden, S. M., Iqbal, M. M., … Travasso, M. I. (2014). Food security and food production systems. In C. B. InField, V. R. Barros, D. J. Dokken, K. J. Mach, M. D. Mastrandrea, T. E. Bilir, … L. L. White (Eds.), *Climate Change 2014: Impacts, adaptation, and vulnerability. Part A: Global and sectoral aspects. Contribution of working group II to the fifth assessment report of the intergovernmental panel on climate change* (pp. 485–533). Cambridge: Cambridge University Press.

Shimono, H., Okada, M., Yamakawa, Y., Nakamura, H., Kobayashi, K., & Hasegawa, T. (2009). Genotypic variation in rice yield enhancement by elevated CO_2 relates to growth before heading, and not to maturity group. *Journal of Experimental Botany*, *60*, 523–532.

Tilman, D., Balzer, C., Hill, J., & Befort, B. L. (2011). Global food demand and the sustainable intensification of agriculture. *Proceeding of National Academy Science U.S.A*, *108*, 20260–20264.

Yoshida, S., & Parao, F. T. (1976). Climatic influence on yield and yield components of lowland rice in the tropics. In *Proceedings of the Symposium on Climate and rice* (pp. 471–494). Los Baños, Philippines: International Rice Research Institute.

Yoshinaga, S., Takai, T., Arai-Sanoh, Y., Ishimaru, T., & Kondo, M. (2013). Varietal differences in sink production and grain-filling ability in recently developed high-yielding rice (*Oryza sativa* L.) varieties in Japan. *Field Crops Research*, *150*, 74–82.