ISSN (Print) 1225-9918
ISSN (Online) 2287-3406
Journal of Life Science 2020 Vol. 30. No. 5. 411~419
DOI : https://doi.org/10.5352/JLS.2020.30.5.411

A Comparison Between the Agricultural Traits of GM and Non-GM Rice in Drought Stress and Non-stress Conditions

Nafula Racheal[1†], Jae-Ryoung Park[1,2†], Dong Won Jeon[1] and Kyung-Min Kim[1,2*]

[1]*School of Applied Biosciences, College of Agriculture and Life Science, Kyungpook National University, Daegu 41566, Korea*
[2]*Coastal Agriculture Research Institute, Kyungpook National University, Daegu 41566, Korea*

Received January 16, 2020 / Revised February 21, 2020 / Accepted February 22, 2020

The development of GM crops has gained significant economic importance, and the number of countries cultivating commercial GM crops has continuously increased since the 1960s. Globally, the area given to cultivating GM soybean, maize, cotton, and canola alone had reached 114 million hectares by 2007. Although the economic importance of cultivating and commercializing GM crops has increased, there is still a need to assess their agricultural traits in comparison to non-GM produce. This study evaluated the agricultural traits of GM rice containing the drought-tolerant gene CaMsrB2 and standard rice to investigate any unintended effects of genetic engineering. The GM and non-GM rice were compared in terms of various agricultural traits in a drought greenhouse and an irrigated paddy field. There was no statistical difference in the field-grown crops, but there was a statistically significant difference in both tiller number and yield in the greenhouse. These results therefore suggest that GM rice lines containing the CaMsrB2 gene are superior in performance to non-GM rice in drought stress conditions and could be grown in drought-prone areas where drought intolerant rice may not be able to grow.

Key words : Drought, GM, non-GM, rice, yield

Introduction

Rice (*Oryza sativa* L.), wheat, and maize are the three leading world food crops; together they directly supply over 42% of all calories ingested by the total human population. From these three earth-shattering crops, rice is by far the most important food crop, it is the essential food crop of greater than half of the world's population - over and above 3.5 billion people depend on rice for more than 20% of their daily calories. Rice being one of the most significant cereal crops, grown in over 100 countries around the world is a staple food for about half of the world's population [2, 18]. With the mushrooming rise in the global population and the deprivation of food, increment in rice yields has become the focal point of rice research and breeding programs [19]. Nevertheless, the per capita increase in global food production has been higher than the increase in population since 1960, due to enormous increases in cereal crop production [37]. This drastic increase in crop yield, known as the Green Revolution, broadly resulted from the advancement of genetically improved high-yielding crop varieties [10], with the very first green revolution which brought rice grain yield to another new level, when it utilized the semi-dwarf 1 gene (sd1) in the 1960s. Even with all these factors, the contradiction between the world food supply and consumer demand has become increasingly sharp, due to the progressively increasing population. There is a projection that global food production must increase by 60-110%[35] come 2050 to be able to feed the growing world population. This is made even more challenging by the decreasing availability of arable land, climate change worldwide and so many other factors. The current climate change, desertification correlated to global warming, dry land soils and salinization of ground water associated with the large-scale agricultural irrigation agriculture all validate that the agricultural environment is rapidly deteriorating [24, 30]. Drought, cold weather and environmental stresses are some of the major factors that hinder crop productivity. Rice as a crop is affected by several biotic and abiotic stresses, and among the numerous abiotic stresses, drought is by far the major

---

[†] **Authors contributed equally.**

***Corresponding author**

Tel : +82-53-950-5711, Fax : +82-53-958-6880
E-mail : kkm@knu.ac.kr

stress which affects its yield significantly under rainfed conditions. Drought in particular is one of the single largest abiotic stress factors causing reduced crop yields and hindering food security worldwide [5] since almost one-third of the earth's land area is either arid or semi-arid. This situation is even made much worse by shortage of water resources due to rampant pollution and drastic climate changes [36, 38]. Agriculture accounts for a large proportion of water usage in arid regions, especially in developing countries, where the percentage of agricultural water can go as high as 90% of the total water consumption. Availability of water is very crucial for agricultural crops to maintain high yields in the varying growing seasons. Water scarcity strongly affects plant and crop production by reducing leaf size, stem extension and root proliferation, disturbing plant water and nutrient relations and hindering water use efficiency [3]. Crop losses during periods of severe drought can be very high and if not regulated could lead to complete crop failure. Drought significantly accounts for 9-10% cereal production losses on a global scale [23] through detrimental effects on plant growth, physiology and grain development [7, 8, 25]. For example, drought, especially water stress of approximately 40% water deficit causes more than 50% rice yield losses [5] globally. The necessity for rice varieties with higher yield potential, and greater yield stability has continued to rise due to the rising human population (9 billion by 2050), and the changing global climate [19]. Therefore, development of drought-tolerant rice cultivars with a higher yield potential is one of the main objectives for rainfed lowland rice breeding programs. Drought tolerant rice crops can be grown in areas where drought sensitive rice crops cannot easily grow, thus sustaining and potentially increasing the area for rice crop production. Conventional breeding approach has some hindrances in developing drought tolerant cultivars [31] for example several cycles are needed to screen for drought. On the other hand, drought tolerant rice varieties can be achieved through molecular breeding to develop a genetically modified (GM) rice variety. Development of GM crops has gained economic importance and the Countries cultivating commercial GM crops have continuously been increasing since the 1960s [14]. The global cultivation area of GM soybean, maize, cotton and canola (oilseed rape), to mention but a few, reached 114 million hectares in 2007 while the total area cropped with GM crops in the European Union (EU) was approximately 110 thousand hectares [13]. Recently, Monsanto developed drought-tolerant corn for commercialization. The *StMYB1* gene from potato [12] *PsAPX* gene from pea [30] *AP37*, *AP59* genes that enhances stress tolerance [28], trehalose biosynthetic gene obtained from *E. coli* [15] and *PUB22, PUB23* from Arabidopsis [4] have already been reported for drought-tolerant crops in Korea. However, issues concerning safety of GM foods have been raised and a precondition for prospective application of GM rice is the fact that genetically stable and phenotypically normal plants are recovered after the transformation process. Undesired effects may be caused by the process of genetic engineering for GM crops [9]. The analysis of phenotypic traits can help in increasing the like-

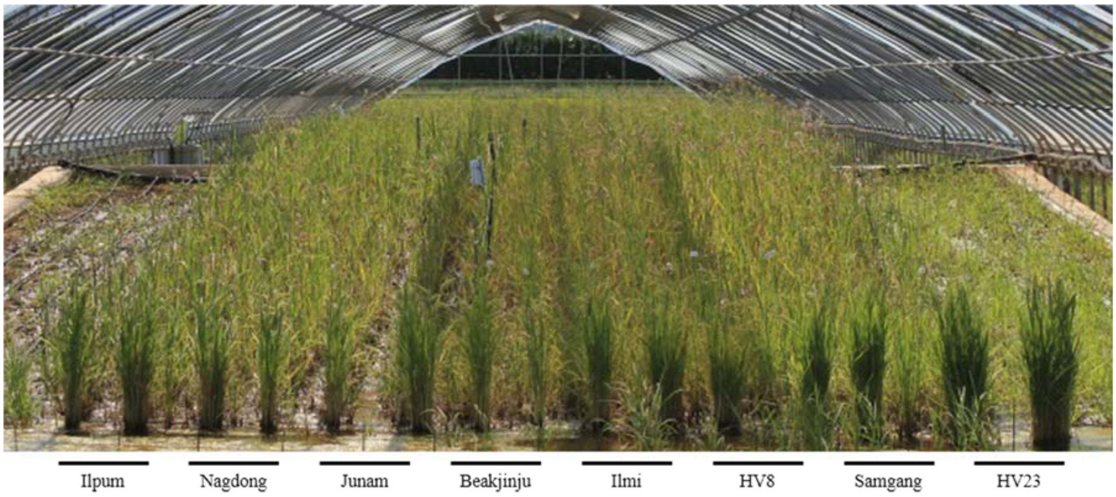

Fig. 1. Phenotype comparison of GM (HV23 and HV8) and non-GM (Ilmi, Samgang, Baekjinju, Junam, Nagdong, Ilpum) rice in drought green house. In the drought green house, GM rice containing *CaMsrB2* gene showed more tiller number than non-GM rice.

lihoods of recognizing unintended effects in dietary composition of the GM crops as it investigates the physiology of plants without any statistical bias [32]. Some GM rice lines have been found to be significantly different from their non-GM parent lines while others were equivalent. Differences between herbicide-tolerant GM rice and the non-transgenic parent rice cultivar were significant in traits such as the flag leaf width, spikelets per panicle, panicle length and harvest index [17]. It was found by [27] that abiotic stress tolerant GM rice plants showed neither growth inhibitions nor visible phenotypic aberrations. A few agronomic traits of some transgenic lines of insect-resistant rice were found significantly different from that of their non-transgenic parent [20]. Another scientist [33] found that a large proportion of most GM rice lines performed poorer than the non-GM controls. Plant height, maturity and panicle initiation of almost all GM lines were significantly different from the control except the average number of tillers which was statistically similar to that of the non-GM control [1]. Oard et al., 2000 [26] found that plant height and maturity were statistically different among hybrid populations of red rice and GM lines as compared to the corresponding populations produced by hybridizing red rice with non-GM rice material. However, to develop drought-tolerant transgenic rice, it is of great value to establish a drought-tolerant transgenic rice guide in the reproductive growth stage of GM field. So many concerns have been raised about the environmental impacts which have not yet been fully assessed for drought tolerant GM plants [39]. Also concerns regarding safety of GM crops have been raised continuously and a precondition for prospective applications of GM rice is the manifestation that genetically stable and phenotypically normal plants are recovered after transformation. For the cultivation of GM rice to advance, transgenic rice should be evaluated in the agricultural environment and the potential concerns should be assessed [21]. Since the effect of a GM plant is unpredictable, the objective of this study was to evaluate the drought tolerant GM rice lines with their non-GM parent in the different agronomic traits under the drought stress treatment carried out in an automated greenhouse and the irrigation treatment carried out in the paddy field. CaMsrB2 gene is known to provide resistance to biological and abiotic environmental stresses. In particular, several experiments have been conducted that are resistant to drought conditions. Drought resistance in GM rice with *CaMsrB2* was excellent in drought resistance and substantially higher plant physiological activities such as photosynthesis and relative moisture content [34]. However, there is no mention of the quantity directly related to the agricultural value of rice, and in this study, various agricultural traits directly related to the agricultural value of GM and non-GM rice with *CaMsrB2* were compared and analyzed

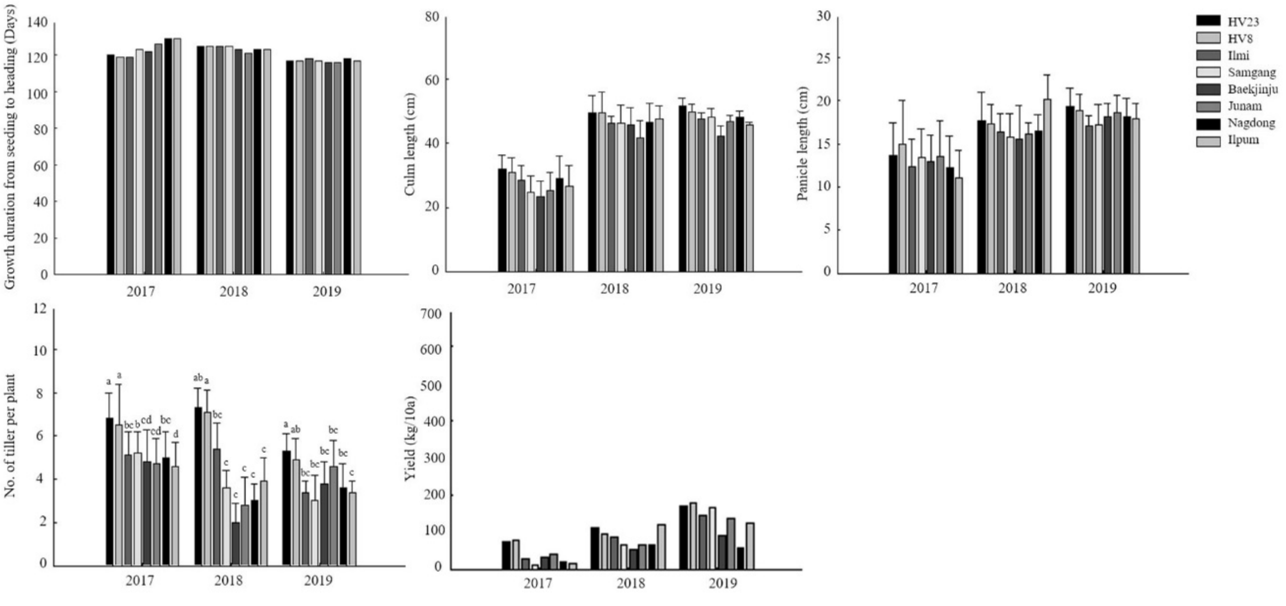

Fig. 2. Heading date, culm length, panicle length, tiller number and yield of GM rice (HV23 and HV8) and non-GM rice (Ilmi, Samgang, Baekjinju, Junam, Nagdong, Ilpum) in drought green house for 3 years 2017, 2018, 2019 Comparative analysis. Bars represent means ± standard error. Means denoted by the same letter are not significantly different ($p>0.05$) as evaluated by Duncan Multiple Range Test (DMRT).

in drought and normal conditions.

Materials and Methods

Location

The experiment was carried out at Kyungpook National University experimental area in Gunwi GM plots (4,700 m2, 360 6´ 41.54´ ´ N, 1280 38´ 26.17´ ´E), where both the greenhouse, and the fields were used to experiment. The automated greenhouse was used for drought stress treatment while the field was used for the irrigation treatment/normal rice growth conditions. The experiment ran for three seasons from 2017, 2018 until 2019. Drought greenhouses were kept as the same as the general fields, while controlling only the quantity of irrigate. Normally, all the doors of the drought greenhouse were opened so that the outside air flowed, and when it rained, the screen was automatically activated to block rainwater from entering the drought greenhouse.

Plant material

This study used two fixed drought tolerant GM lines (HV8 and HV23) of T_8 generation containing drought tolerant gene *CaMsrB2* in chromosome 1 and chromosome 8 respectively, and a non-drought tolerant variety Ilmi in evaluation of the agronomic traits of the two drought GM rice pedigree over a period of three years/three seasons starting from 2017 to 2019 under two treatments. The *CaMsrB2* gene obtained from Capsicum annuum is commended as a novel defense regulator against oxidative stress and pathogen attack [28]. In addition, five representative varieties (Samgang, Baekjinju, Junam, Nagdong, and Ilpum) that were cultivated in Korea were used. It was inoculated in 33℃ dark condition for 3 days, and then seeded in tray. After growing for 4 weeks in the tray, and transplanted to the drought greenhouse and the irrigated paddy field to compare the characteristics of GM rice and Non-GM rice. Each line was planted at a planting density of 30×15 cm, one per line per plant, and herbicide and insecticide spraying, pest control, and package management were cultivated at the county test site in accordance with the RDA standard rice cultivation method. Amount of applied fertilizer was with N-P_2O_4-K_2O = 9.0-4.5-5.7kg / a.

Agronomic trait measurements

The following growth survey methods were used to compare genetic agricultural traits of Ilmi, Samgang, Baekjinju, Junam, Nagdong, Ilpum, HV8, and HV23. The main agricultural traits of rice include heading date, length of culm, length of panicle, number of tiller and yield. Rice heading date of the definition of rice heading date statistics from the initial heading stage to full heading stage. The initial heading stage is 10%(reaching this proportion in the whole

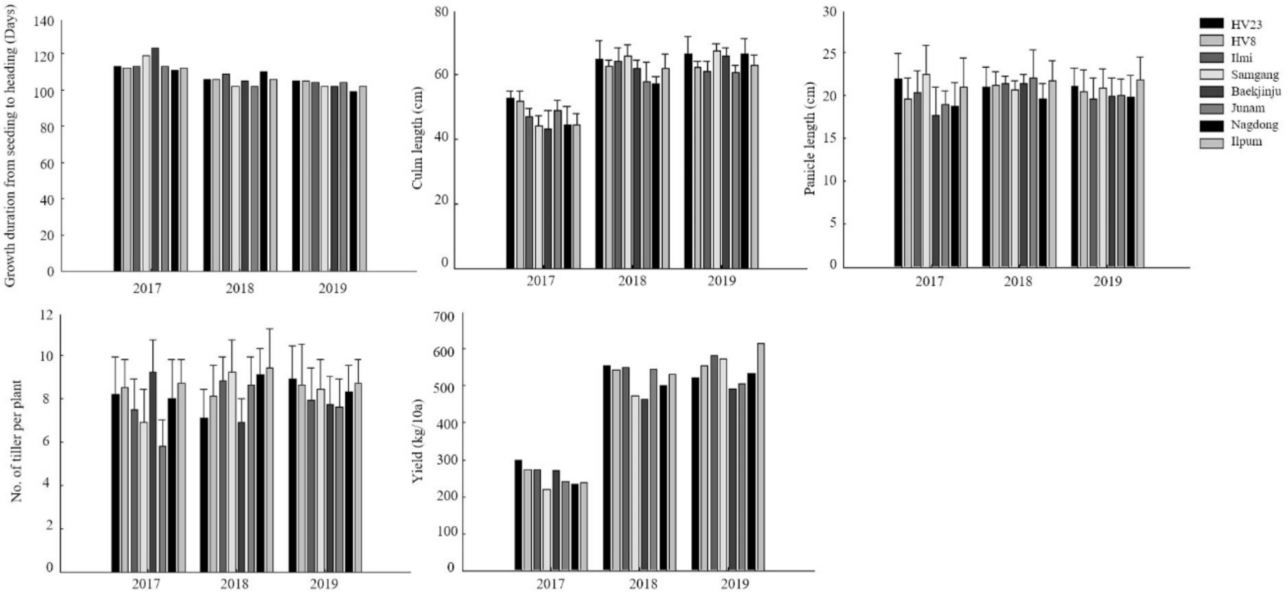

Fig. 3. Heading date, culm length, panicle length, tiller number and yield of GM rice (HV23 and HV8) and non-GM rice (Ilmi, Samgang, Baekjinju, Junam, Nagdong, Ilpum) in irrigated paddy field for 3 years 2017, 2018, 2019 Comparative analysis. Bars represent means ± standard error. Means denoted by the same letter are not significantly different (p>0.05) as evaluated by Duncan Multiple Range Test (DMRT).

line).The heading date is 40%. The full heading stage is 80%. The number of tiller per plant was measured 10 times. The length of culm and length of panicle were also repeated 10 times. Finally, the yield was measured using brown seed weight, moisture content.

Statistical analysis

Data for heading date, culm length, panicle length and tiller number and yield were analyzed using Statistical Package for the Social Sciences (SPSS) 20 statistical package to generate analysis of variance (ANOVA) and significant differences were identified by Duncan's multiple range test (DMRT) at 0.05.

Results

In order to confirm the stable expression and excellence of gene function in the GM rice, HV8, HV23 which have a drought-tolerant gene *CaMsrB2* inserted in Ilmi, and six representative varieties in Korea (Ilmi, Samgang, Baekjinju, Junam, Nagdong, Ilpum) agricultural traits were compared (Fig. 1). Since HV23 and HV8 have inserted the drought tolerant gene *CaMsrB2*, all varieties used in this research were grown in drought-green house and irrigation paddy yields (Fig. 2). The excellence of the GM rice was investigated. Table 1 shows the results of the 2017. In 2017, GM rice HV23 and HV8 did not differ much in Non-GM rice, culm length, and panicle length in both drought green house and irrigated paddy filed. However, the number of tiller of GM rice was higher than that of non-GM rice in a drought green house, and this result also affected the increase in yield. In the irrigated paddy field, there was no significant difference in the number of tillers between GM and non-GM rice. In the drought green house, the average yield of non-GM rice was very low (26.0±9.7), but GM rice HV23 was 76.8 kg/10a and HV8 was 77.4 kg/10a. Non-GM rice and GM rice did not show any significant difference in all of agronomic characters when GM rice and non-GM rice were grown under normal conditions in Irrigated paddy filed (Fig. 3). In 2018, GM and non-GM rice were grown in drought green houses and irrigated paddy field to compare agronomic characters (Table 2). The culm length and panicle length of GM rice HV23 and HV8 were 49.4±5.5, 16.6±3.4 and 46.5±6.5, 17.3±2.2, respectively. These values did not show any significant difference with non-GM rice culm length and panicle length. However, as in 2017, there was a significant difference in number of tiller and yield, with a 5% statistically significant difference between GM rice and non-GM rice. Both number of tiller and yield showed high values of GM rice containing the drought tolerant gene *CaMsrB2*. However, there was no significant difference in culm length, panicle length, number of tiller and yield in all varieties of Irrigated paddy filed. The 2019 survey also showed no significant difference in culm length

Table 1. Comparison of agricultural traits between GM and non-GM rice in drought green house and irrigated paddy field in 2017

	Name of line	Heading date (Days)	Culm length (cm)	Panicle length (cm)	No. of tiller per plant	Yield (kg/10a)
Drought green house	HV23	120	32.0±4.3	13.6±3.8	6.8 ± 1.2^{a}	76.8
	HV8	119	30.8±4.8	14.9±5.1	6.5 ± 1.9^{a}	77.4
	Ilmi	119	28.4±4.6	12.4±3.1	5.1 ± 1.1^{bc}	29.9
	Nagdong	123	24.8±5.1	13.4±3.3	5.2 ± 1.0^{b}	14.5
	Junam	122	23.4±4.9	12.9±3.1	4.8 ± 1.5^{cd}	31.3
	Samgang	126	25.2±5.6	13.5±4.2	4.7 ± 1.2^{cd}	40.6
	Baekjinju	129	29.1±6.8	12.2±3.7	5.0 ± 1.2^{bc}	22.0
	Ilpum	129	26.7±6.3	11.0±3.2	4.6 ± 1.1^{d}	17.8
Irrigated paddy field	HV23	113	52.8±2.3	21.9±2.9	8.2±1.7	298.9
	HV8	112	51.7±3.2	19.6±2.4	8.5±1.3	272.8
	Ilmi	113	46.9±2.8	20.3±2.5	7.5±1.4	272.7
	Nagdong	119	44.4±3.1	22.4±3.4	6.9±1.5	220.7
	Junam	123	43.4±3.9	17.7±3.2	7.2±1.5	272.2
	Samgang	113	48.8±3.3	18.9±1.6	6.8±1.2	240.9
	Baekjinju	111	44.4±3.8	18.7±2.8	7.0±1.8	232.7
	Ilpum	112	44.6±3.4	20.9±3.4	7.7±1.1	239.3

*Mean ± SD, Means followed by a common letter are not significantly different at the 5% level by Duncan Multiple Range Test (DMRT).

and panicle length of GM and Non-GM rice in drought tolerant green house, but 5% statistically significant difference in number of tiller and yield (Table 3). The number of tiller of GM rice, HV23, was 5.3±0.8 and HV8 4.9±1.0, which was higher than that of non-GM rice. The yield of HV23 was 172.7 kg/10a and HV8 was 180.4 kg/10a, which is higher than that of non-GM rice, 100.0±2 kg/10a. There was no significant difference in all agricultural traits in the Irrigated paddy field.

Discussion

The non-significant differences in the agronomic traits such as heading date, culm length, panicle length, tiller

Table 2. Comparison of agricultural traits between GM and non-GM rice in drought green house and irrigated paddy field in 2018

	Name of line	Heading date (Days)	Culm length (cm)	Panicle length (cm)	No. of tiller per plant	Yield (kg/10a)
Drought green house	HV23	125	49.4±5.5	17.6±3.4	7.3±0.9^{ab}	112.4
	HV8	125	49.5±6.5	17.3±2.2	7.1±1.0^{a}	105.4
	Ilmi	125	46.2±2.2	16.4±2.1	5.4±1.2^{bc}	68.9
	Nagdong	125	46.2±5.6	15.8±2.7	3.6±0.8^{c}	66.8
	Junam	123	45.7±5.3	15.5±3.9	2.0±0.9^{c}	55.5
	Samgang	121	41.8±5.2	16.1±1.3	2.8±1.3^{c}	67.7
	Baekjinju	123	46.6±5.8	16.5±1.9	3.0±0.8^{c}	65.3
	Ilpum	123	47.7±4.0	20.1±2.8	3.9±1.1^{c}	48.5
Irrigated paddy field	HV23	106	64.8±5.9	20.9±2.4	7.1±1.3	554.4
	HV8	106	62.5±1.9	21.1±1.6	8.1±1.4	543.5
	Ilmi	109	64.2±4.0	21.4±0.8	8.8±1.1	550.6
	Nagdong	102	65.8±3.5	20.6±1.1	9.2±1.5	472.3
	Junam	105	62.1±2.5	21.4±1.0	6.9±1.1	464.3
	Samgang	102	58.0±5.8	22.0±3.3	8.6±1.3	545.7
	Baekjinju	110	57.3±2.2	19.5±1.8	9.1±1.2	500.3
	Ilpum	106	62.1±4.4	21.7±2.3	9.4±1.8	530.6

*Mean ± SD, Means followed by a common letter are not significantly different at the 5% level by Duncan Multiple Range Test (DMRT).

Table 3. Comparison of agricultural traits between GM and non-GM rice in drought green house and irrigated paddy field in 2019

	Name of line	Heading date (Days)	Culm length (cm)	Panicle length (cm)	No. of tiller per plant	Yield (kg/10a)
Drought green house	HV23	117	51.5±2.5	19.3±2.1	5.3±0.8^{a}	172.7
	HV8	117	49.7±2.5	18.8±1.9	4.9±1.0^{ab}	180.4
	Ilmi	118	47.5±2.0	17.0±1.2	3.4±0.5^{bc}	103.9
	Nagdong	117	48.1±2.8	17.2±2.3	3.0±1.2^{bc}	113.8
	Junam	116	42.3±3.2	18.1±1.6	3.8±1.0^{bc}	92.1
	Samgang	116	46.8±1.8	18.6±2.0	3.6±1.2^{bc}	118.2
	Baekjinju	118	48.0±1.9	18.1±2.1	3.6±1.1^{bc}	58.9
	Ilpum	117	45.6±0.8	17.9±1.7	3.4±0.5^{c}	114.1
Irrigated paddy field	HV23	105	66.3±5.4	21.0±2.1	8.9±1.5	562.7
	HV8	105	62.3±1.9	20.4±2.5	8.6±1.9	555.6
	Ilmi	104	61.1±3.2	19.6±2.4	7.9±1.5	561.2
	Nagdong	102	67.4±2.3	20.8±2.2	8.4±1.4	565.3
	Junam	102	65.9±2.6	19.9±2.1	7.7±1.3	512.7
	Samgang	104	60.8±2.0	20.0±1.9	7.6±1.3	511.5
	Baekjinju	99	66.6±4.6	19.8±2.5	8.3±1.2	532.4
	Ilpum	102	63.1±2.9	21.8±2.6	8.7±1.1	530.2

*Mean ± SD, Means followed by a common letter are not significantly different at the 5% level by Duncan Multiple Range Test (DMRT).

Table 4. Comparative analysis of agricultural traits between GM and non-GM rice in drought green house and irrigated paddy field for 3 years 2017, 2018, 2019

	Name of line	Heading date (Days)	Culm length (cm)	Panicle length (cm)	No. of tiller per plant	Yield (kg/10a)
Drought green house	HV23	120.7±4.0	49.3±1.5	16.3±3.1	6.3±1.2^{a}	131.8±21.6^{a}
	HV8	120.3±4.2	47.7±2.3	16.3±2.1	6.0±1.0^{ab}	136.9±29.4^{a}
	Ilmi	120.7±3.8	45.3±2.1	15.0±2.6	4.3±1.2^{ab}	68.7±16.2^{b}
	Nagdong	121.7±4.2	46.3±1.5	15.0±2.0	3.7±1.2^{ab}	68.7±8.30^{b}
	Junam	120.3±3.8	43.3±1.5	15.0±3.0	3.3±1.2^{b}	56.7±14.6^{b}
	Samgang	121.0±5.0	43.3±2.5	15.7±2.5	3.7±0.6^{ab}	63.0±21.3^{b}
	Baekjinju	123.3±5.5	46.3±1.5	15.3±3.1	3.7±1.2^{ab}	58.3±6.50^{b}
	Ilpum	123.0±6.0	46.0±1.0	14.3±3.1	3.7±0.6^{ab}	73.3±7.50^{ab}
Irrigated paddy field	HV23	108.0±4.4	64.3±1.5	20.7±0.6	8.0±1.0	528.3±21.7
	HV8	107.7±3.8	61.7±0.6	20.0±1.0	7.7±0.6	563.3±22.7
	Ilmi	108.7±4.5	62.3±1.5	20.0±1.0	7.7±0.6	550.3±30.5
	Nagdong	107.7±9.8	64.7±2.1	20.7±1.2	7.7±1.5	532.7±53.5
	Junam	114.5±8.9	62.7±2.1	19.0±2.0	7.0±1.2	476.0±14.4
	Samgang	106.3±5.9	59.0±1.0	20.0±2.0	7.0±1.0	528.0±20.7
	Baekjinju	106.7±6.7	56.7±0.6	18.7±0.6	8.3±0.6	518.0±16.4
	Ilpum	106.7±5.0	62.0±1.0	20.7±0.6	8.3±0.6	522.3±8.6

*Mean ± SD, Means followed by a common letter are not significantly different at the 5% level by Duncan Multiple Range Test (DMRT).

number under drought stress treatment and irrigation treatment and yield under irrigation treatment of GM (HV8 and HV23) rice lines and non-GM (Ilmi) rice cultivar suggested that insertion of *CaMsrB2* gene did not cause any unintended effects in the GM lines. However, there was a significant difference between GM rice and non-GM rice in drought green house. In particular, GM rice containing *CaMsrB2* maintained more yield and number of tillers compared to non-GM rice under drought conditions. However, as 2017, 2018, and 2019, the increase in yield and the numbers of tillers have changed. This is because yield is influenced not only by genes but also by environmental effects [22]. One of the basic requirements in commercializing a GM crop is the proof of its substantial equivalence with its non-GM parent. Substantial equivalence of GM and non-GM Crops (ISAAA. Pocket K No. 56. 2018) (FAO. 2008). Few studies have shown that insertion of some transgenes caused significant changes in many traits of GM rice. GM and non-GM rice lines started and completed heading in almost the same period. It should be noted that it took more than 10 days to complete heading within the same rice line while the variation among rice lines took 3 days at most. Our results regarding heading dates coincide with previous observations by Dhungana et al., 2015 [6] on comparative study of *CaMsrB2* gene in transgenic rice and non-transgenic counterpart. Ectopic expression of rice *MADS* genes in transgenic rice lowered the heading date to varying levels [16]. Although some agronomic parameters like culm length, tiller number and panicle length showed a cultivars difference, there were no statistically significant differences in GM lines compared to the non-GM counterpart in both treatments. Our results in these parameters coincide with the results by Oh et al., 2009 [28] where it was found that there were no major differences in the vegetative growth during overexpression of *AP37* under drought conditions. It was found by Oh et al., 2005 [27] that abiotic stress tolerant GM rice plants showed neither growth inhibitions nor visible phenotypic aberrations. A few agronomic traits of some transgenic lines of insect-resistant rice were found significantly different from that of their non-transgenic parent [20]. Another researcher [33] found that a large proportion of most GM rice lines performed poorer than the non-GM controls. Plant height, maturity and panicle initiation of almost all GM lines were significantly different from the control except the average number of tillers which was statistically similar to that of the non-GM control [1]. Oard et al., 2000 [26] found that plant height and maturity were statistically different among hybrid populations of red rice and GM lines as compared to the corresponding populations produced by hybridizing red rice with non-GM rice material. The significant differences in the yield under drought stress treatment in the automated greenhouse of GM (HV8 and

HV23) rice lines and non-GM rice cultivar suggested that insertion of drought-tolerant *CaMsrB2* gene led to improvement in yield production under drought stress treatment. Transgenic rice plants expressing *SNAC1* [11] and *OsLEA3* [40], showed improvement in grain yield under field drought conditions. It showed be noted that the *CaMsrB2* gene is commended as a novel defense regulator against oxidative stress and pathogen attack [29]. Plants respond and later adapt to abiotic stress so as to survive adverse conditions [28].

Acknowledgement

This work was supported from agency of LMO environmental risk assessment (PJ014830012020), Rural Development Administration, Republic of Korea.

The Conflict of Interest Statement

The authors declare that they have no conflicts of interest with the contents of this article.

References

1. Bashir, K., Husnain, T., Fatima, T., Latif, Z., Mehdi, S. A. and Riazuddin, S. 2004. Field evaluation and risk assessment of transgenic indica basmati rice. *Mol. Breed.* **13**, 301-312.
2. Carvalho, F. P. 2006. Agriculture, pesticides, food security and food safety. *Environ. Sci. Policy* **9**, 685-692.
3. Chaves, M. M., Maroco, J. P. and Pereira, J. S. 2003. Understanding plant responses to drought from genes to the whole plant. *Funct. Plant Biol.* **30**, 239-264.
4. Cho, S. K., Ryu, M. Y., Song, C., Kwak, J. M. and Kim, W. T. 2008. Arabidopsis PUB22 and PUB23 are homologous U-Box E3 ubiquitin ligases that play combinatory roles in response to drought stress. *Plant Cell.* **20**, 1899-1914.
5. Daryanto, S., Wang, L. and Jacinthe, P. A. 2017. Global synthesis of drought effects on cereal, legume, tuber and root crops production: A review. *Agric. Water Manage.* **179**, 18-33.
6. Dhungana, S. K., Kim, B. R., Son, J. H., Kim, H. R. and Shin, D. H. 2015. Comparative study of *CaMsrB2* gene containing drought-tolerant transgenic rice (Oryza sativa L.) and non-transgenic counterpart. *J. Agron. Crop Sci.* **201**, 10-16.
7. Fahad, S., Bajwa, A. A., Nazir, U., Anjum, S. A., Farooq, A., Zohaib, A. and Saud, S. 2017. Crop production under drought and heat stress: plant responses and management options. *Front. Plant Sci.* **8**, 1147.
8. Farooq, M., Hussain, M. and Siddique, K. H. 2014. Drought stress in wheat during flowering and grain-filling periods. *Crit. Rev. Plant Sci.* **33**, 331-349.
9. Haslberger, A. G. 2003. Codex guidelines for GM foods include the analysis of unintended effects. *Nat. Biotechnol.* **21**, 739.
10. Hedden, P. 2003. The genes of the Green Revolution. *Trends Genet.* **19**, 5-9.
11. Hu, H., Dai, M., Yao, J., Xiao, B., Li, X., Zhang, Q. and Xiong, L. 2006. Overexpressing a NAM, ATAF, and CUC (NAC) transcription factor enhances drought resistance and salt tolerance in rice. *Proc. Natl. Acad. Sci.* **103**, 12987-12992.
12. Im, J. S., Cho, K. S., Cho, J. H., Park, Y. E., Cheun, C. G., Kim, H. J. and Byun, M. O. 2012. Growth, quality, and yield characteristics of transgenic potato (Solanum tuberosum L.) overexpressing StMyb1R-1 under water deficit. *Plant Biotechnol.* **39**, 154-162.
13. James, C. 2007. Global status of commercialized biotech/GM crops, 2007 (Vol. 37): ISAAA Ithaca, NY.
14. James, C. 2009. Brief 41: Global status of commercialized biotech/GM crops: 2009. ISAAA Brief. Ithaca, NY: International Service for the Acquisition of Agri-biotech Applications. 290.
15. Jang, I. C., Oh, S. J., Seo, J. S., Choi, W. B., Song, S. I., Kim, C. H. and Nahm, B. H. 2003. Expression of a bifunctional fusion of the Escherichia coli genes for trehalose-6-phosphate synthase and trehalose-6-phosphate phosphatase in transgenic rice plants increases trehalose accumulation and abiotic stress tolerance without stunting growth. *Plant Physiol.* **131**, 516-524.
16. Jeon, J. S., Lee, S., Jung, K. H., Yang, W. S., Yi, G. H., Oh, B. G. and An, G. 2000. Production of transgenic rice plants showing reduced heading date and plant height by ectopic expression of rice MADS-box genes. *Mol. Breed.* **6**, 581-592.
17. Jiang, X. and Xiao, G. 2010. Detection of unintended effects in genetically modified herbicide-tolerant (GMHT) rice in comparison with non-target phenotypic characteristics. *Afr. J. Agric. Res.* **5**, 1082-1088.
18. Jiao, Z., Si, X. X., Li, G. k., Zhang, Z. M. and Xu, X. P. 2010. Unintended compositional changes in transgenic rice seeds (Oryza sativa L.) studied by spectral and chromatographic analysis coupled with chemometrics methods. *J. Agric. Food Chem.* **58**, 1746-1754.
19. Khush, G. S. 2005. What it will take to feed 5.0 billion rice consumers in 2030. *Plant Mol. Biol.* **59**, 1-6.
20. Kiani, G., Nematzadeh, G. A., Ghareyazie, B. and Sattari, M. 2009. Comparing the agronomic and grain quality characteristics of transgenic rice lines expressing cry1Ab vs. non-Transgenic controls. *Asian J. Plant Sci.* **8**, 64.
21. Lee, H. S., Yi, G. H., Park, J. S., Seo, S. C., Sohn, J. K. and Kim, K. M. 2011. Analysis of the weediness potential in vitamin A enforced rice. *Kor. J. Weed Sci.* **31**, 160-166.
22. Lee, K. J., Kim, D. J., Ban, H. Y. and Lee, B. W. 2015. Genotypic differences in yield and yield-related elements of rice under ElevATED air temperature conditions. *KJAFM.* **17**, 306-316.
23. Lesk, C., Rowhani, P. and Ramankutty, N. 2016. Influence of extreme weather disasters on global crop production. *Nature* **529**, 84.

24. Long, S. P. and Ort, D. R. 2010. More than taking the heat: crops and global change. *Curr. Opin. Plant Biol.* **13**, 240-247.
25. Matiu, M., Ankerst, D. P. and Menzel, A. 2017. Interactions between temperature and drought in global and regional crop yield variability during 1961-2014. *PLoS One* **12**, e0178339.
26. Oard, J., Cohn, M. A., Linscombe, S., Gealy, D. and Gravois, K. 2000. Field evaluation of seed production, shattering, and dormancy in hybrid populations of transgenic rice (Oryza sativa) and the weed, red rice (Oryza sativa). *Plant Sci.* **157**, 13-22.
27. Oh, S. J., Song, S. I., Kim, Y. S., Jang, H. J., Kim, S. Y., Kim, M. and Kim, J. K. 2005. Arabidopsis CBF3/DREB1A and ABF3 in transgenic rice increased tolerance to abiotic stress without stunting growth. *Plant Physiol.* **138**, 341-351.
28. Oh, S. J., Kim, Y. S., Kwon, C. W., Park, H. K., Jeong, J. S. and Kim, J. K. 2009. Overexpression of the transcription factor AP37 in rice improves grain yield under drought conditions. *Plant Physiol.* **150**, 1368-1379.
29. Oh, S. K., Baek, K. H., Seong, E. S., Joung, Y. H., Choi, G. J., Park, J. M. and Choi, D. 2010. *CaMsrB2*, pepper methionine sulfoxide reductase B2, is a novel defense regulator against oxidative stress and pathogen attack. *Plant Physiol.* **154**, 245-261.
30. Park, H., Kim, Y., Choi, M., Lee, J., Choi, I., Choi, I. and Kwon, S. 2009. Chloroplast-targeted expression of PsAPX1 enhances tolerance to various environmental stresses in transgenic rice. *Kor. J. Breed. Sci.* **41**, 261-270.
31. Ribaut, J. M., Jiang, C., Gonzalez-de-Leon, D., Edmeades, G. and Hoisington, D. 1997. Identification of quantitative trait loci under drought conditions in tropical maize. 2. Yield components and marker-assisted selection strategies. *Theor. Appl. Genet.* **94**, 887-896.
32. Rischer, H. and Oksman-Caldentey, K. M. 2006. Unintended effects in genetically modified crops: revealed by metabolomics? *Trends Biotechnol.* **24**, 102-104.
33. Shu, Q. Y., Cui, H. R., Ye, G. Y., Wu, D. X., Xia, Y. W., Gao, M. W. and Altosaar, I. 2002. Agronomic and morphological characterization of Agrobacterium-transformed Bt rice plants. *Euphytica* **127**, 345-352.
34. Siddiqui, Z. S., Cho, J. I., Park, D. B., Lee, G. S., Ryu, T. H., Shahid, H. and Park, S. C. 2015. Field assessment of *CaMsrB2* transgenic lines in a drought stress environment. *Turk. J. Bot.* **39**, 973-981.
35. Tilman, D., Balzer, C., Hill, J. and Befort, B. L. 2011. Global food demand and the sustainable intensification of agriculture. *Proc. Natl. Acad. Sci.* **108**, 20260-20264.
36. Trenberth, K. E., Dai, A., Van Der Schrier, G., Jones, P. D., Barichivich, J., Briffa, K. R. and Sheffield, J. 2014. Global warming and changes in drought. *Nat. Clim. Chang.* **4**, 17-22.
37. Trewavas, A. J. 2001. The population/biodiversity paradox. Agricultural efficiency to save wilderness. *Plant Physiol.* **125,** 174-179.
38. Woodward, A., Smith, K. R., Campbell-Lendrum, D., Chadee, D. D., Honda, Y., Liu, Q. and Chafe, Z. 2014. Climate change and health: on the latest IPCC report. *Lancet* **383**, 1185-1189.
39. Wraight, C., Zangerl, A., Carroll, M. and Berenbaum, M. R. 2000. Absence of toxicity of Bacillus thuringiensis pollen to black swallowtails under field conditions. *Proc. Natl. Acad. Sci.* **97**, 7700-7703.
40. Xiao, B., Huang, Y., Tang, N. and Xiong, L. 2007. Over-expression of a LEA gene in rice improves drought resistance under the field conditions. *Theor. Appl. Genet.* **115**, 35-46.

초록 : 건조 스트레스 환경과 스트레스가 없는 환경에서 GM벼와 non-GM벼의 농업 형질 비교

나폴라 레이칠[1†] · 박재령[1,2†] · 전동원[1] · 김경민[1,2*]
([1]경북대학교 농업생명과학대학 응용생명과학부, [2]경북대학교 해안농업연구소)

GM 작물의 개발은 경제적 중요성을 갖게 되었고 상업적인 GM 작물을 재배하는 국가들은 1960년대 이후 지속적으로 증가하고 있다. 비록 GM 작물의 경작과 상업화는 경제적 중요성을 얻었지만, 여전히 non-GM 작물에 비해 그들의 농업적 특성을 평가할 필요가 있다. 본 연구는 유전공학에서 사용된 방법의 결과로 발생할 수 있는 의도하지 않은 문제 발생 여부를 확인하기 위해 내건성 유전자 *CaMsrB2*를 포함한 GM 쌀과 non-GM 쌀의 농업적 특성을 내건성 온실과 관개수답에서 평가했다. 관개수답에서는 GM벼와 non-GM벼의 모든 농업형질에서 유의미한 차이가 없었다. 그러나 내건성온실에서 수수와 수량에서 GM벼와 non-GM벼에서 유의미한 차이가 있었다. 따라서 본 연구 결과는 *CaMsrB2* 유전자를 함유한 GM벼가 내건성 조건에서 non-GM 쌀에 비해 경제적 가치가 우수하다는 것을 시사한다. 이 결과는 또한 *CaMsrB2* 유전자를 함유한 GM 벼는 가뭄에 취약한 지역에서 안정적으로 수량을 유지 하면서 재배 가능 하다.