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Responses of rice yield and grain quality to high temperature in open-top chamber to predict impact of future global warming in Thailand

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Abstract

The research was aimed to study effects of high temperature range in comparison with the ambient conditions (about 2-4 °C at daytime and 1-2 °C at nighttime) obtained from the chosen open-top chamber (OTC) design on maturity stage of rice such as maturity growth indexes, yield attributes and grain quality characteristics. The rice grown outside the OTC was used as a control sample. Other key parameters of environment (solar radiation and relative humidity) were also determined for inside and outside the OTC. At daytime, the solar radiation inside the OTC was 249.79-171.90 Wm^{-2}, which corresponds to 55.18 - 46.02 % of RH from August to December in 2014, respectively. The temperature range was from 35.75 – 31.84 °C in this period. At nighttime, the RH was 88.62-75.23 % and the temperature was 27.87-22.96 °C. There was a well- linear relationship between inside and outside for all parameters. It appeared that high temperature (35.74-31.84 °C at daytime and 27.87-22.96 °C at nighttime) inside the OTC during crop period significantly decreased number of tiller per pot and increased height of plant at maturity stage. The percentage of ripen panicle, length of panicle, and number of spikelet per panicle were significantly greater than those of control plants. However, the weight of 1,000 seeds was decreased and the percentage of unfilled grain inside the OTC increased, compared to rice outside, showing the way of a reduction in rice yields and qualities. The total carbohydrate of grains was decreased, while the protein and ash content increased. There were no significant difference of the moisture of rice grains and fat content while the color of grains was significantly different between inside and outside the OTC. The appearance of rice paddy inside was greener than that of outside.

Keywords: Global warming, nighttime, daytime, high temperature, rice yield, rice qualities, open-top chamber.
Abbreviations: OTC_open-top chamber, NT_nighttime, DT_daytime, RH_relative humidity

Introduction

Global climate changes would cause a number of problems for agriculture activities. One of the most important components of such a change is the increase of temperature along with the effect of greenhouse. According to IPCC (2001), with the emissions of greenhouse gases, the temperature could increase in the range of 1.8-5.8 °C. For plant growth especially for rice production, such increase would influence the productivity, quality and food security in the future.

In Asian countries, rice is one of the main plants contributing to the income of farmers and the countries. The effects of high temperature on yield loss have been studied in recent years. Three stages namely vegetative, reproductive, and grain filling or ripening phase are normally divided for crop growth cycle (Yoshida et al., 1981). The number of panicles per plant, number of spikelets per panicle, grain filling rate and total grain weight are usually applied for determination of the rice grain yield (Kim et al., 2009). Under high air temperature, the spikelet fertility and grain filling could be damaged (Saini and Aspinall, 1982; Jagadish et al., 2007). The negative effect of high temperature could be shown on the seed setting rate, grain-filling duration, and qualities of rice grains (Matsui et al., 1997a,b). Previously, high temperature conditions could shorten the grain-filling duration, which led to a reduction in weight of rice grain (Kobata and Uemuki, 2004). Therefore, the influence would be existed at the post-harvest stages such as milling, milled rice kernel appearance and grain qualities. Additionally, other problems of the increased temperature is about chalky core in the kernel (Cooper et al., 2008), which totally affect cooking process and eating quality, subsequently bringing an awareness for industrial millers or market consumers

Grain yields of both *indica* and *japonica* ecotypes were reduced by different elevated temperatures both daytime and nighttime. A reduction in rice yield under the increased temperature has been already reported in various investigations especially in response to nighttime temperature increment (Mohammed and Tarpley, 2009; Peng et al., 2004; Prasad et al., 2006). Peng et al. (2004) reported a decrease of 15% in grain yield for each 1 °C rise in minimum temperature. Shah et al. (2014) confirmed that a temperature variation of about 2 °C can lead to significant yield losses. Focusing on all day, nighttime and daytime warming, Dong et al. (2011) documented that a temperature increase of less than 2 °C affects rice productivity in East China. Besides the high temperature, the differences of other climatic factors such as radiation and humidity could contribute to variation of rice yield.

The open-top chamber (OTC) has been an approved as a design for assessing the effect of climate change on plants since the 1970s (Heagle et al., 1973; Heyneke et al., 2012). The OTC is cylindrical enclosures that allow the air quality to be modified while the ambient climatic conditions can be maintained (Heyneke et al., 2012). With a few parts of artificiality of OTCs, this technique can provide a uniform microclimate close to ambient conditions.

In a study on global warming and rice production, the setting of temperature increment was usually above 4 ^oC, which may not represent the expecting increase in the near future (Shah et al., 2014). Meanwhile, the effects of global warming on the temperature increase at field level are necessarily assessed for future rice production (Rehmani et al., 2011). The changes in range of temperature from 2-4 ^oC should be carried out to study the responses of rice since the temperature of environment does not constantly change at specific unit. Also, studying on climate change provides more information on how global warming influences the grain yield formation (Chen et al., 2011). On the other hand, the effect of increase temperature on rice depends on rice cultivars, crop season and area. In Thailand, such a research has not been studied in advance. The full picture from the pre-harvest to post-harvest site of rice on such of temperature increase has been limited. Regarding to scenario by 2050 (IEA, 2013), it could be an idealistic target on rice productivity and marketability in near future when high temperature treatments in the range of 2-4 ^oC is studied by our chosen design of OTC.

The objective of this study were (1) to determine temperature and other environmental parameters of chosen OTC design, and (2) study the effect of such high temperature changes on maturity stage of rice such as maturity rice growth indexes, rice yields and grain qualities.

Results and Discussion

Temperature profiles of ambient air and inside open-top chamber during crop period

The temperature inside and outside the open-top chamber (OTC) were continuously recorded from August to December in 2014, which are shown at Fig. 1. At daytime (DT), the highest average temperature inside the OTC was observed in October while the lowest average temperature was in December. The difference of temperature between inside and outside the OTC at DT was greater than that of nighttime (NT). However, the trend of temperature changes was similar between inside and outside the OTC at those periods. The temperature inside the OTC was constantly higher than that of outside indicated that there was a clear relationship between the temperature difference and other parameters such as relative humidity and solar radiation.

The maximum temperature elevation in the OTC was approximately 2-4 ºC at DT, while at NT the difference between air temperatures inside and outside OTC was about 1–2 ºC. The temperature in the OTC could be well-controlled compared to those in similar systems. According to Fig. 2, the maximum temperature outside the OTC was lower than that of inside for both NT and DT. The highest maximum temperature at DT was in October, November, and December and followed by the rest, while the maximum temperature at NT was in September. Meanwhile, the highest minimum temperature was in September for both NT and DT. At DT, there was a large difference between inside and outside the OTC. The temperature above 30 ^oC is generally not appropriate for ripening (Osada et al., 1973). Morita et al. (2005) reported that grain weight was more harmful under high night temperatures (22/34 ^oC, day/night) than high day temperatures (34/22 ^oC) and control conditions (22/22 ^oC).

According to Table 1, the range of temperature difference between inside and outside the OTC specifically was 1.85-3.39 ^oC at DT, while it was 0.8-1.51^oC at NT. The greatest difference was in September (3.39 ^oC at DT and 1.51 ^oC at NT) and October (3.14 ^oC at DT and 1.3 ^oC at NT). In August, there was no rice grown inside the OTC and the temperature difference between inside and outside was at least (1.85 ^oC at DT and 0.8 ^oC at NT). The period from September to October was corresponding with the vegetative stage of rice growth while that of October to early December was in the stage from flowering initiation to ripening stage in this study. The results indicated that the vegetative stage caused a larger difference of temperature inside and outside the OTC at both DT and NT when compared to the rest, especially at the vegetative stage. Similarly to the previous studies, the effects of such increased temperature had a marked effect on rice growth indexes (Unsworth et al., 1984; Chaturvedi et al., 2010).

Solar radiation and relative humidity changes during crop growth period

According to Fig. 3a, solar radiation outside the OTC was higher than that of inside. The solar radiation was highest in August, then decreased in September and increased again in October. Two months remained had a lowest solar radiation when compared to the counterparts in which December had a lower solar radiation than November. In general, higher solar radiation led to a higher maximum temperature and a lower minimum temperature which may be due to radiative cooling. According to previous studies, crop growth and yield depend on solar radiation through photosynthesis. Higher temperature could be associated with higher radiation, which influenced amount of N per unit leaf area. It is well-known that higher radiation use efficiency is associated with higher contained amount of N per unit leaf area, which is related to respiration of rice, influenced by temperature difference. In the study to identify the reasons for such yield reduction, Shah et al. (2014) found that the yield reduction was observed for the years with lower incident radiation during the rice growth period.

The solar radiation range inside the OTC was 249.79-171.90 Wm^{-2} at daytime, which corresponds to 34.61-31.84 ^oC of temperature and 55.18 - 46.02 % of RH from August to December 2014 (Table 2). The difference of solar radiation between inside and outside the OTC during this period was from 31.65 to 22.20%. There seemed to have a clear relationship between three of these parameters; however, there was a small fluctuation change in each parameter when compared to the others.

The RH inside the OTC was higher than that of outside at both NT and DT. A large difference was found from October to December (Fig. 3b). Moreover, in comparison between DT and NT inside the OTC, the RH at NT was higher than that of DT suggested the effect of temperature and light level on RH, which is similar to previous researches for the similar system. Furthermore, at DT, the RH inside the OTC increased from 5.3, 1.7, 10.1, 13.6 and 9.6 compared to that of outside, corresponding with August, September, October, November, and December. This could be ascribed partly to the increase in temperature at DT and partly to the natural ventilation inside the OTC. Differences in RH between ambient and inside the OTC were minimal in September, which may be due to the fact that ventilation units were running at low speed at this period. Moreover, this period was the beginning period of transferring the rice pots into the chamber.

Relationship of environmental parameters inside and outside the chamber

There was a linear relationship between inside and outside for all parameters in this study (Table 3). The better linear correlation was found at NT for temperature (R^2 = 0.984) and RH (R^2 = 0.931) inside and outside the OTC. Moreover, a high correlation was found for solar radiation (R^2 = 0.908) at DT. The temperature and RH at DT seemed to be less fitted when compared to those at NT. This suggested the effect of other factors, rather than light level from the sun, causing such fluctuations.

High linear relationship of solar radiation between inside and outside proved the efficiency of material cover, allowing light through inside effectively. Meanwhile, the linear relationship of other parameters (temperature and relative humidity) indicated that efficiency of the chosen design in controlling studied factors.

The OTC is cylindrical enclosures that can provide two major benefits; the microclimate inside the OTC can be modified and controlled, which are close to the ambient climate condition (Heyneke et al., 2012). Similar to previous studies, the OTC facility proved well for the purpose of its design. The recorded average temperature inside the OTC was approximately 2-4 ºC higher than ambient at DT and 1-2 ºC at NT. The friendly-use and maintenance of system in terms of naturally controllable technique has proved its practicality well. This confirmed the fact that with a minor portion of artificiality, the OTC represents a relatively low-cost with a uniform microclimate close to ambient conditions (Heyneke et al., 2012). However, although OTC in this study provided a natural field-like condition, the environmental conditions still fluctuated from ambient conditions.

Plant responses to the changes of climate parameters

Plant growth attributes at maturity

The plant growth attributes were determined at maturity stage and the results are shown at Table 4. High yield of rice is associated with increasing aboveground biomass production (Akita, 1989; Amano et al., 1993). Previous researchers proved that the hybrid rice have about 15% higher yield than inbreds, which is mainly due to an increase in biomass production. According to Table 4, the height of rice plant and number of rice tiller per pot were significantly different between inside and outside the OTC, while there was no significant difference for weight of dried plant body and length of root at the maturity stage.

The rice grown outside had a lower height average but a higher number of rice tiller per pot than inside. These results were similar to the research of Osada et al. (1973) which also reported that the plant height increased with the rise of temperature within the range of 30–35^{o}C. Moreover, in a recent study, Oh-e et al. (2007) reported that the plant height was more increased under high temperature than under ambient temperature condition. High temperatures, especially at DT, increased the plant height at maturity stage, which is also agreed with the research of Shah et al. (2014). The high temperature at DT associated with increase in the plant height could be attributed to the rapid elongation of internode, linked to the internal hormones such as ethylene and gibberllins (Qi et al., 2011; Shah et al., 2014). In addition, Cheng et al. (2009) found that plant height significantly increased in rice when grown under high temperature at NT.

More tillers were counted for outside the OTC at the ripening stage in this study. Interestingly, the number of tiller per pot outside was higher than that of inside while the number of panicle was not significantly different (Table 5). This meant that several tillers did not have panicle at the harvest time. This confirmed that the high temperature could reduce the development of unproductive tiller. These results agreed with the research of Oh-e et al. (2007) who found that at maturity, the number of tillers under high-temperature conditions is lower than that under ambient conditions.

It is well-known that unproductive tillers compete with productive tillers for assimilates, solar energy, and mineral nutrients, particularly nitrogen. Moreover, they are related to the increase of moist in the environment and damaged insect growth (Mew, 1991). The tiller production in rice crop are influenced by leaf area index and plant N status (Zhong et al., 2002), which was controlled by light intensity and/or light quality. The tillering was simulated by high light intensity at the base of the canopy (Yoshida, 1981; Graf et al., 1990). Rice with a suitable number of tillers is supported to have more uniform panicle size, efficient use of horizontal space and a larger proportion of high-density grains (Padmaja Rao, 1987; Janoria, 1989). In this study, such a different phenomenon was observed at the harvest stage of rice grown inside and outside the OTC; however, the magnitude of the potential contribution to yield by eliminating unproductive tillers was not quantified.

Yield attributes

Different yield attributes were determined for rice at maturity stage, which are shown at Table 5. Although a higher number of tiller per pot were found for rice grown outside the OTC than inside, there was no significant difference of number of panicle for two places (mentioned earlier). However, the rest of yield attributes was significantly different when inside and outside compared. The percentage of ripen panicle, length of panicle, ratio of branch to length, number of grains per panicle inside were significantly greater than those of outside. The percentage of unfilled grains outside the OTC was remarkably decreased and the final weight of grains was significantly increased. Moreover, the color of final grains was yellower when the rice was grown outside the OTC.

These results were similar to the effect of high temperature according to previous studies. High temperature influences on grain-filling duration, grain weight, and density grains per panicles (Ahn, 1986; Padmaja Rao, 1987; Slafer et al., 1996). Moreover, high temperature could also reduce spikelets fertility (Shah et al., 2014). The reduction was affected by both high temperatures at DT and NT. Previously, several cultivars in *indica* ecotype showed variation in the number of panicles with a rise in the temperature. Baker et al. (1992) reported the number of panicles increased as minimum (night time) when temperature increased. In this study, number of panicles inside the OTC seemed to be greater than that of outside although insignificant difference was obsereved. Peng et al. (2004) found a negative linear relationship between spikelets m^{-2} and daily minimum temperature; however, the researchers did not find out any relationship between spikelets per panicle and daily maximum or minimum temperatures.

Table 1. Different temperature between inside chamber and ambient air at daytime and nighttime*.

Item	August	September	October	November	December
Inside temperature at DT (°C)	34.61	35.03	35.74	34.53	31.84
Outside temperature at DT (°C)	32.76	31.65	32.60	31.93	28.76
Inside temperature at NT (°C)	25.87	27.87	26.15	25.98	22.96
Outside temperature at NT (°C)	25.07	26.36	24.86	24.91	22.13
Different daytime	1.85	3.39	3.14	2.60	3.08
Different nighttime	0.80	1.51	1.30	1.07	0.83

DT = daytime; NT = nighttime *data was recorded during the period year of 2014

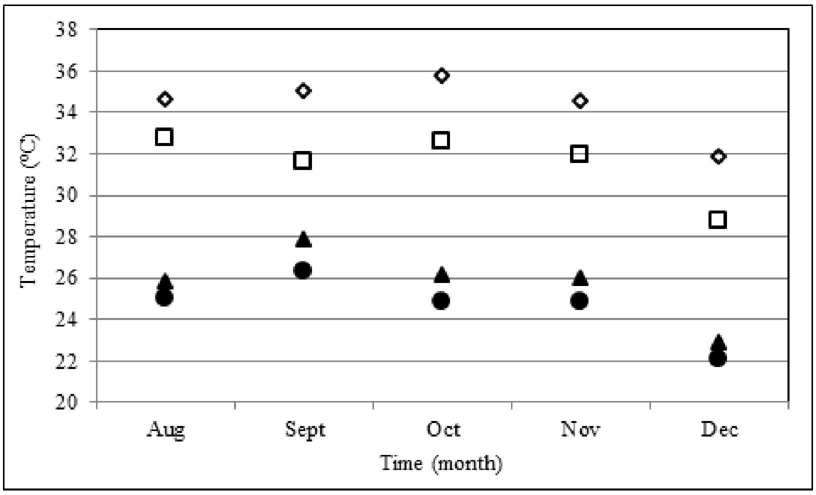
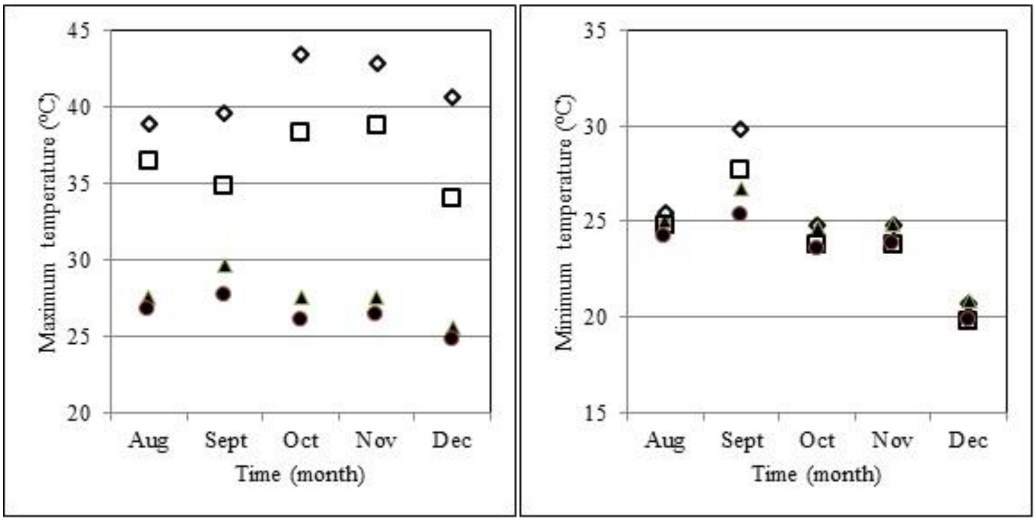


Fig 1. Changes of temperature during experimental period (◊ = inside temperature at daytime; □ = outside temperature at daytime; ▲= inside temperature at nighttime; ● = outside temperature at nighttime).

Table 2. Different RH and solar radiation between inside and ambient air

	Item	August	September	October	November	December
RH (%)	Inside daytime	55.18	54.90	48.63	53.13	46.02
	Outside daytime	52.26	53.96	43.73	45.89	41.59
	Inside nighttime	88.62	83.30	84.77	85.18	75.23
	Outside nighttime	87.36	81.50	79.93	79.92	69.64
	Different daytime (%)	5.29	1.71	10.08	13.63	9.62
	Different nighttime (%)	1.43	2.16	5.71	6.17	7.42
Solar radiation (Wm^{-2})	Inside daytime	249.79	194.79	247.16	180.85	171.90
	Outside daytime	365.45	253.02	323.35	261.11	220.95
	Different daytime (%)	31.6	23.0	23.6	30.7	22.2

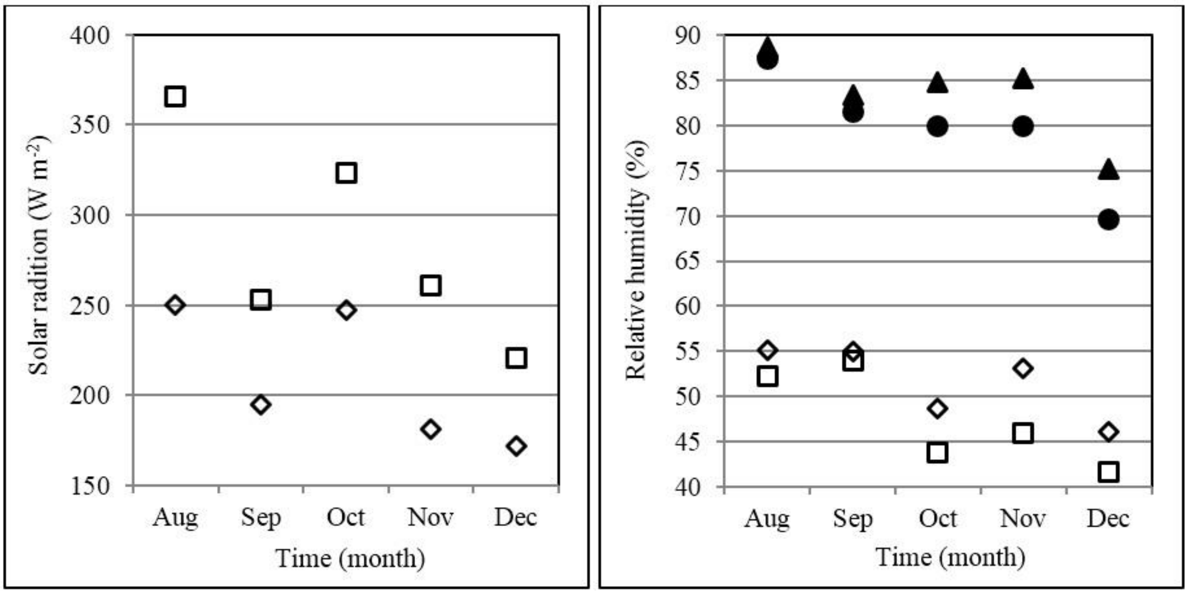


(a) (b)

Fig 2. Changes of maximum (a) and minimum temperature (b) during experimental period (◊ = inside temperature at daytime; □ = outside temperature at daytime; ▲= inside temperature at nighttime; ● = outside temperature at nighttime).

Table 3. Correlation of environmental parameters between inside and outside the chamber.

Inside	Outside	Equation	R^2
Temperature at daytime (°C)	Temperature at daytime (°C)	Y = 1.011 X – 3.196	0.859
Temperature at nighttime (°C)	Temperature at nighttime (°C)	Y = 0.868 X + 2.301	0.984
RH at daytime (%)	RH at daytime (%)	Y = 1.213 X – 15.06	0.836
RH at nighttime (%)	RH at nighttime (%)	Y = 1.238 X – 23.61	0.931
Solar radiation at daytime (W/m^2)	Solar radiation at daytime (W/m^2)	Y = 1.502 X – 29.03	0.908



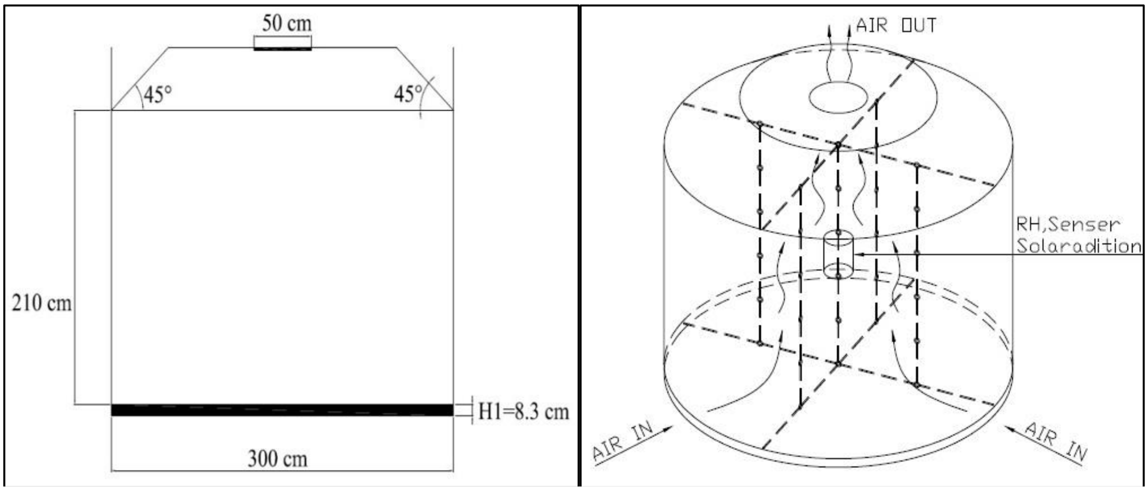
(a) **(b)**

Fig 3. Changes of solar radiation (a) and relative humidity (b) during experimental period (◊ = inside light intensity and RH at daytime; □ = outside light intensity and RH at daytime; ▲= inside RH at nighttime; ● = outside RH at nighttime).

Table 4. Different maturity plant growth attributes inside and outside the chamber.

	Height of plant (cm)	No. tiller per pot	Length of root (cm)	Weight of dried body (g)
Inside	90.93±4.16a	9.33±2.89a	28±1.56a	28.2±2.89a
Outside	83.43±8.17b	14.27±3.43b	27.87±1.69a	30.44±4.35a

Values are mean ± Std.
Values followed by different letters are significantly different for *t*-test at 95% level confidence.



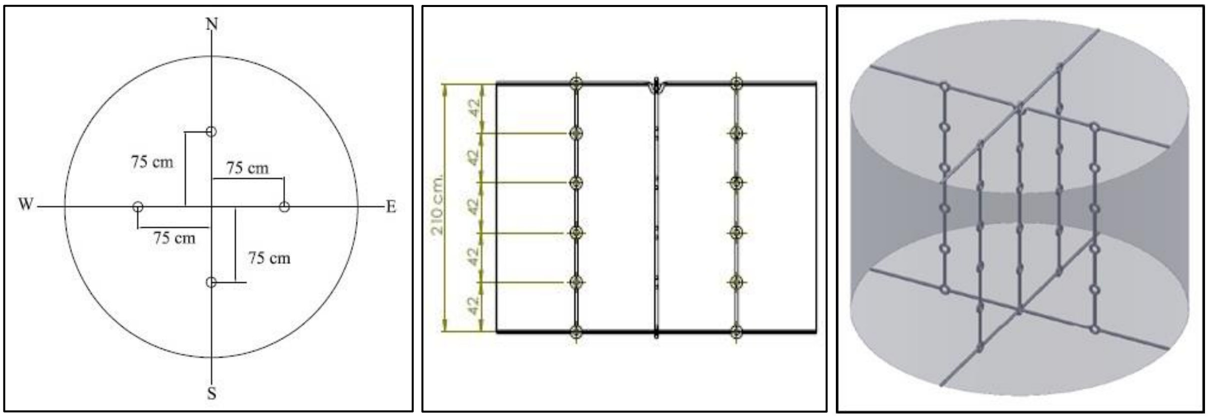
(a) **(b)**

Fig 4. Scheme of the OTC systems for design (a) and assumed air flow stream inside the OTC (b).

Table 5. Different yield attributes inside and outside the chamber.

	No. panicle	% ripen panicle	length of panicle (cm)	Ratio of branch to length (%)	Weight of 1,000 seeds	No. spikelets per panicle	% unfilled grains
Inside	8.8±2.7a	89.23±14.09a	22.77±1.61a	37.22±3.04a	23.91±0.81b	92.55±20.14a	29.84±9.99a
Outside	7.5±3.1a	69.21±25.85b	21.85±2.15b	36.36±2.17a	25.4±1.07a	81.02±17.44b	17.87±10.38b

Values are mean ± Std. Values followed by different letters are significantly different for *t*-test at 95% level confidence.



(a) **(b)** **(c)**

Fig 5. Positions of sensors inside the chambers at different views: (a) = surface cross-section; (b) = horizontal cross-section; (c) = 3D view

Table 6. Different grain qualities inside and outside the chamber

	Moisture	Protein (x 5.95) (%)	Fat (%)	Ash (%)	Total carbohydrate (%)	L*	a*	b*
Out.	1.65 ± 0.06[a]	6.40 ± 0.07[a]	3.34 ± 0.02[a]	1.44 ± 0.05[a]	87.19 ± 0.02[b]	55.88±0.43a	5.09±0.32a	27.97±0.25b
Ins.	1.47 ± 0.01[a]	8.69 ± 0.06[b]	3.58 ± 0.31[a]	1.72 ± 0.04[b]	84.55 ± 0.35[a]	53.9±0.48b	7.33±0.24b	30.31±0.39a

Values are mean ± Std.Values followed by different letters are significantly different for *t*-test at 95% level confidence.Out. = outside chamber; Ins. = inside chamber

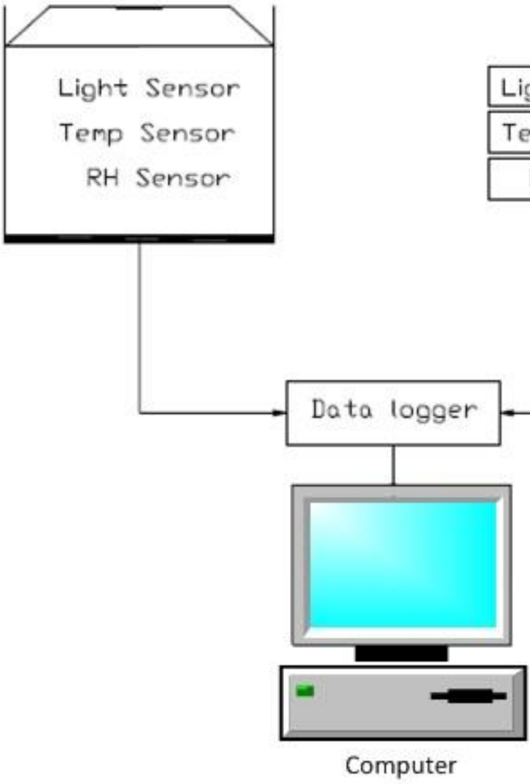


Fig 6. Feature of data record system including sensors of light, temperature, and relative humidity inside and outside the OTC.

In this study, among the yield components, the most pronounced effect of increased temperature was found on the percentage of unfilled grains and weight of 1,000-seeds. As it was predictible, high temperature treatments significantly reduced the weight of 1,000-seeds and increased percentage of unfilled grains. During grain-filling period, high temperature is a critical factor to reduce grain filling/ripening (Kobata and Uemuki, 2004). The ripened rice grains under ambient temperature had a higher weight than those under high temperature treatment, which was likely an effect of heat stress (Shah et al., 2014). A similar effect of yield attributes in response to different temperature increments has been reported earlier in several other studies (Osada et al., 1973; Yoshida et al., 1981; Kobata and Uemuki, 2004; Zhu et al., 2005; Yamakawa et al., 2007; Shah et al., 2014).

Grain qualities

Apart from plant growth index and rice yield attributes, the grain qualities such as appearance (color) and nutrition characteristics (moisture, protein, lipid, ash, and carbohydrate content) are also important factors regulating the popularity and marketability.

The moisture of rice grains and fat content were not significantly different while the protein, ash, total carbohydrate and color of grains were significantly different between inside and outside the OTC. The protein content seemed to be oppositely different with the total carbohydrate. Although no significant difference in moisture content of grains between inside and outside, the weight of 1,000-grains outside were significantly higher than that of inside (mentioned earlier). The lightness (L*) of grains inside was lower than that of outside, while a* and b* values were higher. With the values of color, the appearance of rice paddy inside chamber was greener than outside.

The cellular and developmental processes were influenced by high temperature leading to reduced fertility and grain quality (Barnabas et al., 2008). Decreased grain weight, reduced grain filling, higher percentage of white chalky rice and milky white rice are common effects of high temperature exposure during ripening stage in rice (Osada et al., 1973; Yoshida et al., 1981; Kobata and Uemuki, 2004). In addition, the high temperature also causes serious reduction in grain size and amylose content (Yamakawa et al., 2007; Zhu et al., 2005), which related to the reduction of grain weight. The phenomena are due to the fact that under high temperature condition, the respiratory demand of the seeds requires excessive energy consumption (Tanaka et al., 1995). Alternatively, the reduction in grain weight is attributed to higher grain dry matter accumulation rate. The process was taken place together with a shortened grain-filling period (Kobata and Uemuki, 2004). In this study, the high temperature on rice crop exposure also affected the crop duration with low accumulated carbohydrate and weight of seeds; however, the high temperature increased the protein and ash content.

Materials and Methods

Plant material

Rice cultivar, *Oryza sativa* L, an *indica* type was used in this study. The rice seeds were obtained from Phitsanulok Rice Research Center, Phitsanulok province, Thailand.

Experimental site

The experiment was performed at the Faculty of Agriculture Natural Resource and Environment, Naresuan University, Muang District, Phitsanulok Province (16°74’52’’ N, 100° 19’68’’ E). The experiment time was conducted during rice growth season from August to December in 2014.

Chamber design

The OTCs consist of metal constructions with transparent vertical side-walls (polycarbonate), and a frustum on top. An opening in the middle of the frustum (50 cm of diameter) allows an air exchange to reduce temperature and humidity effects in the chamber. The cylindrical Zinc coated steel framework of 300 cm height and 300 cm diameter was covered with 0.18 cm thick polycarbonate sheet (210 cm x 1,000 cm = width x length). The sunlight transmission through the polycarbonate sheet proved to be approximate 80% of the photosynthetic active radiation at the beginning. Covered with the polycarbonate sheet, the chamber has a volume of 33.2 m^3. The frustum with an angle 45° and 65 cm height towards inside the chamber was maintained to reduce the dilution effect of the air current within the chamber (Fig. 4). The lower portion of chamber (H_1-adjustable) was also opened for natural ventilation. In this study, the difference of temperature inside and outside the open-top chamber was preliminarily studied. The ratio of open top diameter to lower open portion area was 1:4, which was chosen in this study to obtain the different temperature range of approximate 2-4 °C. Scheme of the open-top chamber system for open-top chamber is illustrated at Fig. 4.

Determination of temperature, relative humidity, and solar radiation

Positions of temperature sensors were set up as Fig. 5, which involves: 6 sensors on vertical line at the center of chamber with a distance between each sensor of 42 cm, 6 sensors on vertical line with a distance between each sensor of 42 cm corresponding with North, West, South, and East direction Fig. 5a, b, c. The distance from the sensor line at the center to the sensor line at different directions is 75 cm. 1 light sensor and 1 humidity sensor were placed at the middle position on vertical line of chamber (Fig. 4b). Two these sensors were also set up at the same height with that of outside while 6 sensors of temperature outside were positioned at the same height with 6 sensors of temperature inside chamber at the center. There were 39 sensors in total including inside (as shown at Fig. 5) and outside the chamber.

The higher temperature inside the OTC was preliminarily studied by varying the ratio of open top diameter to open lower portion area. The ratio of 1:4 was then chosen in this study to obtain the temperature range of approximate 2-4 °C higher than the ambient air. The solar radiation range inside the OTC was 249.79-171.90 Wm^{-2} which corresponds to 55.18 - 46.02 % of RH from August to December in 2014.

The sensors were connected through the data logger (CR10, Campbell Scientific Co., UT, USA) with the automatic data collection. The frequencies in data collection were within10 min per time unit. The data collection was continuously recorded for 5 months from August to December in 2014. Thermocouple (A3537-L, Type T Thermocouple wire, Campbell Scientific Co., UT, USA) was set to record temperature. Solar radiation was recorded by solar sensor (LI200X Pyranometer, Campbell Scientific Co., UT, USA), and relative humidity were measured with a humidity transmitter (HMD60, Vaisala Co., Helsinki, Finland).

Plant preparation

Plant cultivar was exposed to the selected OTC. Rice plants were grown at ambient conditions to the age of 15 days. The rice plants were then moved to plastic pots (25 cm x 23 cm x 17 cm = open diameter x height x bottom diameter) filled with clay soil. One seedling per pot and 30 pots per treatment was carried out. The pots of rice were fixed in 3 rows with certain space between rows.

Data record and analysis

Rice was grown outside for 15 days and then moved inside the chamber on 6^{th} September in 2014. The record was conducted during vegetative stage, flowering initiation to the ripening stage. The frequency in data collection (temperature, humidity and solar radiation) was recorded continuously from August to December in 2014. Feature of experimental measurements is shown at Fig. 6. For temperature, the mean data was averaged at different directions and positions.

Plant grow, rice yield attributes and qualities of rice grains

Plants were harvested at maturity stage to assess different attributes. At maturity, rice in each pot was determined for plant growth index, rice yield attributes, and quality of grains. The value of those attributes was determined for 15 pots randomly. All analyses were carried out at least in duplicate and the data was shown as mean value of 15 pots with standard deviation.

Maturity plant growth*:* height of plant (cm), number of tiller per pot, length of root, and weight of dried plant body per pot. At the final harvest, the pot was collected randomly and plants were counted from each pot. The height of plant and the length of root after gentle soil removal process were determined by metal scale ruler. After rice panicles and roots were separated, the dried weight of body was determined by oven-drying at 70 °C to constant weight.
Yield attributes*:* number of panicle, percentage of ripen panicle, length of panicle, ratio of branch to length, weight of 1,000-seeds, number of spikelet per panicle, percentage of unfilled grains. Filled spikelets and unfilled spikelets were separated by submerging in tap water then oven-dried at 70 ^{o}C to constant weight to determine dry weight. Percentage of unfilled grain was calculated as the ratio of the unfilled grain to the total grains.
Grain qualities*:* color of rice paddy, moisture content of grains (925.45 AOAC, 2012), percentage of protein (991.20 AOAC, 2012), percentage of fat (2003.05 AOAC, 2012), percentage of ash (938.08 AOAC, 2012), and total carbohydrate by difference, including crude fiber (In house method based on AOAC, 2005 by calculation). Color of rice paddy was measured by Hunter-Lab colorimeter XE-scan (Chromameter model CR-300, Japan). Measurement was based on the CIE-LAB system with color values of L^*, a^* and b^* display according to Le et al. (2014). Grain subsamples from the harvested area were oven-dried to constant weight at 70 ^{o}C.

Statistical analysis

The data was shown by mean with standard deviation. Two-sample comparison with *t*-test at 95% level confidence was used to compare means by STATGRAPHICS Centurion Version XVI (StatPoint Technologies, Inc. Warrenton, VA 20186, USA).

Conclusion

The chosen open-top chamber (OTC) design proved well for the purpose of its design. The temperature was naturally controllable by ratio of open top diameter to open lower portion area. The recorded average temperature inside the OTC was approximately 2-4 ºC higher than ambient at daytime and 1-2 ºC at night time. High temperature inside chamber significantly decreased number of tiller per pot, and weight of 1,000-seeds. The percentage of ripen panicle, length of panicle, number of spikelet per panicle inside were significantly greater while percentage of unfilled grain was significantly lower than those of outside. The high temperature also significantly reduced total carbohydrate of grains while increase protein and ash content. The moisture of rice grains and fat content were not significantly different; however, the color of grains was significantly different between inside and outside the OTC. The appearance of rice paddy inside the OTC was greener than that of outside. Remarkably, the weight of seeds was significantly lower than that of outside chamber indicating the way of a reduction of rice yields.

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