Effect of Rising Global Temperature on Dry Mass Loss of Stored Paddy

M.G.G. Awanthi, S.B. Navaratne, B.M.S.Jinendra, C.M. Navaratne

Abstract— The scope of this study was to assess the dry mass loss (DML) of stored paddy at different temperatures coupled with rising global temperature and to identify adaptation techniques to curb this loss. Three conditions were analyzed according to the split-split plot design, where the variety (AT-362 & Kuruluthuda), the processing technique (raw & parboiled paddy), and the storage temperature levels (26ºC, 30ºC, 34ºC, 38ºC) were varied. About 5 kg of paddy of each variety at 14% moisture content were packed in poly sacks and stored in temperature-controlled chambers for 6 months. Moisture content and 1000-grain weight of paddy were determined monthly to calculate DML. Data were analyzed using SAS software package. Results revealed that DML of raw paddy was increased with the increase of temperature from 26ºC to 38°C and it was significantly higher ($P < 0.05$) when paddy was stored at 38ºC than 26ºC. Further, DML is merely doubled when storage temperatures were increased from 26ºC to 38ºC in raw paddy. As long as DML of paddy is less than 0.8%, they remain under good keeping quality. Under this circumstance, AT-362 and Kuruluthuda can be stored for 119 and 129 days at 26ºC and 41 and 46 days at 38ºC, respectively. The DML of stored raw paddy can be expressed in an equation as a function of temperature, variety, and time. The result revealed that DML of Kuruluthuda variety was less than that of AT-362 at each temperature. However, DML of parboiled paddy was significantly lower ($P<0.05$) than raw paddy in both varieties at 30ºC, 34ºC, and 38ºC. Therefore, parboiling and identifying heat resistance paddy varieties can be introduced as an adaptation techniques to control DML at high temperature levels.

Index Terms— Adaptation, AT-362 & Kuruluthuda, Dry mass loss, High temperature, Storage

1 Introduction

RICE is considered as a staple food of approximately 3.5 billion people worldwide. Over 100 countries were cultivated rice and more than 90% of the world's rice production is recorded in Asia. Furthermore, more than 3 billion Asians fulfil around 35–75% of the calories through consuming rice [1]. Besides the role for food security, rice is a primary source of income and employment for more than 200 million households across countries in the developing world [2]. Global per capita rice demand is constant at about 65 kg according to the recent estimations [3]. However, production of rice will be a challenging issue in rice-growing areas, particularly in Asia, which produces more than 90 percent of the world's rice, due to the temperature increase coupled with continued climate change [4].

According to the multiple independently produced datasets, averaged combined land and ocean surface temperature has increased from 0.85 to 2ºC, over the period of 1880 to 2012 globally [5]. A scenario of relatively high greenhouse gas emissions called RCP (Representative Concentration Pathways) 8.5 predicted that global mean surface temperature will increase 2.6 to 4.8ºC from the year 2081 to 2100 [6]. More common day time maximum temperature in tropical belt area is around 32°C and it rarely exceeds 35ºC [7]. According to global warming predictions, the ambient air temperature in rice production regions can be increased than 35ºC within next 100 years. [8] Peng et al. (2004) found that paddy yield reduce by 10% due to increasing daily maximum and minimum temperature by 1ºC. Furthermore, rice quality can be degraded due to increment in chalky kernels and alterations of head and broken rice distribution at high temperature [9]. Beside the yield, rising temperature can be a serious economic threat even on post-harvest operations, including harvesting, drying, processing, pest and disease management, packaging and storage [10].

Among the different post-harvest activities in paddy, storage can be influenced by the rising global temperature. Although there is a slow rise in storage temperature when outside temperature increase, substantial deterioration can be occurred due to rising temperature frequently for long time. Storing paddy appropriately for long time is of urgent need because farmers tend to stock paddy as a market-linked asset due to increasing up the market price of paddy usually until the next harvest [10]. For instances, considerable quantity of world rice ending stocks were estimated at every year and it was 171.3 million tons in 2016-2017 [11]. However, [12]Cruz and Diop. (1989) revealed that the diurnal variations in temperature can be highly affected grains stored in structures which walls were made using aluminium, galvanized sheet iron or asbestos cement sheets, due to their low thermal inertia. [13]Sawant et al. (2012) found that the after 12 months, temperature of wheat grain stored inside a silo increased from 29.30ºC to 42.90ºC while cover with plinth storage increased from 29.30ºC to 39.94ºC due to respiration of grains and insects. This temperature gradient caused to translocate the moisture and then deteriorative changes occurred from local accumulation of exces-

- *M.G.G Awanthi is currently pursuing masters degree program in Food Science and technology in University of Jayawardhanapura, Sri Lanka, PH-094772548252. E-mail: mggawanthi@gmail.com*
- *S.B. Navaratne is currently a Professor in Department of Food Science in University of Jayawardhanapura, Sri Lanka, PH-094775095610. Email: sbnava1234@yahoo.com*
- *B.M.S. Jinendra is currently a Senior Lecturer in Department of Agricultural Engineering in University of Ruhuna, Sri Lanka, PH-094772601126. E-mail: jinendrata@yahoo.com*
- *C.M Navaratne is currently a Professor in Department of Agricultural Engineering in University of Ruhuna, Sri Lanka, PH-094718116982. Email: champa_m2004@yahoo.com*

sive moisture [14]. Beside this rapid deterioration, increasing storage temperature would result in short safe storage period, and declining of vitality in paddy [15].

It is generally accepted that increasing temperature greatly affects the respiration of stored grains and breakdown process in stored products. Respiration rate of stored grains doubles for each 5°C increase in temperature, up to about 28°C and above this temperature it begins to decline [12]. However, corn stored at 10 to 30°C with 14 to 22% moisture showed around doubled rate of respiration with each 10°C increment in temperature [16]. Since the structural carbohydrates of the foods combust in respiration process, DML can occur with quality degradation of harvested foods. Therefore, respiration of the grain is the foremost process to be controlled just after harvesting. [15]Gao et al. (1999) found that DML of paddy increased with increasing storage temperature within the range of 10°C to 30°C. Similar effect has explored by [16]Navaratne et al. (2013) that dry mass loss rate of paddy, green gram corn and cowpea stored at higher temperature (>35°C) for 4 months, are higher due to rapid rate of respiration. Furthermore they investigated that the rate of dry mass loss of paddy was less at low temperatures, preferably less than 30°C. Dry mass loss is a good parameter to determine the quality of rough rice and it can be used to develop maximum allowable storage time guidelines for paddy [18]. Therefore, understanding the effect of temperature on DML of stored paddy is vitally important.

Considerable evidences exist to prove the negative effects of increasing temperature on paddy yield; however a little is understood about the effects on stored paddy. Hence, the main objectives of this study was to assess the dry mass loss of stored paddy at possible ambient temperatures (26, 30, 34, and 38ºC) in future and to identify adaptation techniques for minimizing DML at storage level

2 Methodology

2.1 Experimental procedure

The study was conducted at Faculty of Agriculture, University of Ruhuna, Sri Lanka. AT-362 (an improved paddy variety) and Kuruluthuda (a traditional paddy variety) were selected considering their abundance in the designated experimental area. About 240 kg of fresh paddy harvested in Maha season (2016/2017) were collected, cleaned, and dried down to get moisture content around 14%. Then, the paddy was divided into two portions and one portion of each was parboiled by soaking, steaming and drying. Firstly, two portions of each variety were soaked in cold water for 48 hours and water was replaced every 12 h to control microbial activities. Then soaked water was drained off and steamed for about 4 to 6 min. The parboiled paddy was dried under sun as a thin layer (approximate thickness 1cm) until moisture content reaches to 18%. After that, paddy were heaped up and kept for tempering. Finally, paddy was sun dried again to get the final moisture content around 14%.

Temperature-controlled chambers were fabricated to store paddy. Electrical heat energy source, Arduino micro controller system and DHT 11 temperature and relative humidity sensors were equipped in the chambers to maintain the even temperature and to record temperature and relative humidity. Since average monthly temperature variation is from 26ºC to nearly 32ºC during last 10 years at the study area, 26ºC was selected as the lowest temperature measuring level of the experiment. As germination capacity of cereal grains is destroyed at temperatures over 40ºC [12] and the ambient air temperature in rice production areas would be raised more than 35ºC within next 100 years, 38ºC was selected as the upper temperature measuring level of the experiment. Therefore, selected temperature levels of the temperature controlling chambers in the study were 26, 30, 34 and 38ºC. Finally, 5 kg of parboiled and raw paddy of each variety were packed in poly sack bags (0.45 m x 0.3 m) and stored at mentioned temperature levels in temperature-controlled chambers for 6 months.

2.2 Data collection and DML analysis

Three samples were drawn from upper, middle, and bottom parts of each 5 kg of paddy bags using sample trier (Model: OSK 10197) to determine the DML. Samples were drawn at 4 weeks intervals for a period of 6 months and determined moisture content as well as 1000 grain weight, as these two parameters are important to calculate DML of grains during storage. Moisture content was determined using gravimetric method under the temperature of 130ºC for 20 h with whole grains [19]. Thousand grain count of paddy was taken from granometer (Model: OSK10200: Type B) and weight of these grains were determined using electrical balance. Finally, the DML was calculated using the Equation 1 [15].

$$DML = \frac{\lfloor G1\ (1 - W1) - G2\ (1 - W2) \rfloor}{G1\ (1 - W1)}\ x\ 100\% \quad (1)$$

Where: DML = Dry mass loss rate (% dry basis), G1 = 1000 grain weight (g), G2 = 1000 grain weight after storage (g), W1 = The grain moisture content of the sample (%), W2 = The grain moisture content after storage %

[20]Teter (1982) suggested that the deterioration should not exceed 0.8% DML at the end of the storage time. Therefore, maximum allowable storage time was determined by estimating the storage time required to lose 0.8% dry matter in paddy stored at different temperature levels.

2.3 Data analysis

All statistical analyses were performed in SAS software package. The study was conducted according to split-split plot design while replicating all treatments thrice. The variety is the main plot factor with 2 levels (AT-362, Kuruluthuda), processing technique is the sub plot factor with 2 levels (raw, parboiled) and temperature is the sub-sub plot factor with 4 levels (26ºC, 30ºC, 34ºC, and 38ºC). The entire experiment included 48 samples. Data were analyzed by three way analyzing of the variance (ANOVA) using the PROC GLM procedure and Means were separated using Duncan multiple range test.

Correlation analyses were performed to evaluate the relationship between DML and storage parameters. Furthermore, multiple linear regression analyses were conducted to develop equations to predict DML of paddy stored at different temperatures in different period of storage. All obtained regression coefficients were tested using 2 tail T test at 0.05 probability level.

3 Results

Results of the split-split plot analysis revealed that 3 factors interaction (Variety*Processing technique*Temperature) was significant in first month ($F_{3,24}$=3.49, $P<0.05$), second month ($F_{3,24}$=14.99, $P<0.05$), third month ($F_{3,24}$=4.88, $P<0.05$), fourth month ($F_{3,24}$=3.77, $P<0.05$) fifth month ($F_{3,24}$=4.07, $P<0.05$) and sixth month ($F_{3,24}$=3.64, $P<0.05$) during the storage period. Therefore, any lower order interactions and main effects involving terms of the significant interaction were not considered.

The results for mean comparisons of the three factor interaction effects of DML rate of two paddy varieties in raw and parboiled form stored at 4 temperature levels for 6 months are shown in Table 1. The rate of DML is steadily increasing with the time for both paddy varieties at each temperature level. The highest DML was shown at 38ºC in raw AT-362 variety (2.695 ± 0.066) after 6 months and the least at 26 ºC in parboiled Kuruluthuda paddy variety (0.022 ± 0.012) after a one month. The rate of DML found to be increased with temperature only in raw form of both paddy varieties and it was significantly higher ($P< 0.05$) at 38ºC compared to DML at 26ºC during six month period of storage. Furthermore, when storage temperature was increased from 26ºC to 38ºC (by 12ºC), rate of DML in both raw paddy varieties were more than doubled until 3rd month for AT-362 and 4th month for Kuruluthuda. It was recorded as 4.0, 9.6, 5.5, 3.0, 1.0, and 0.7 times higher than the initial DML in raw Kuruluthuda and 7.8, 14.1, 2.1, 1.3, 1.2, and 8.0 times higher than initial DML in raw AT-362 from first to sixth month respectively. Moreover, AT-362 shows higher DML than the Kuruluthuda stored at 38ºC for 6 months (Table 1).

As shown in Table 1, DML of parboiled AT-362 and Kuruluthuda were ranging from 0.028±0.012% to 0.062±0.020% and 0.022±0.012% to 0.083±0.003%, respectively, during the six months storage. DML of parboiled paddy of both varieties was remarkably lower than ($P>0.05$) raw paddy at each temperature levels and each month. However, no significant difference was found between raw and parboiled paddy of AT-362 kept at 26ºC during the first two months. Similarly, raw and parboiled paddy of Kuruluthuda, which was kept at 26ºC were not significantly different during the first three months.

According to the results pertaining to the DML (Table 2), the highest maximum allowable storage time (129 days) was recorded by Kuruluthuda at 26ºC while the lowest was AT-362 (41 days) at 38ºC. This means when storage temperature is increasing, maximum allowable storage time is also reciprocally decreasing. However, DML of parboiled paddy in both varieties were less than 0.8% DML (022±0.012% - 0.083±0.003%) as shown in Table 1. Therefore, maximum allowable storage time for parboiled paddy would be more than 6 months irrespective of temperature increment.

TABLE 1

Rate of DML of two types of paddy varieties in raw and parboiled form stored at 4 temperature levels for 6 months.

Storage time (Month)	Storage temperature (ºC)	DML*(%); mean ± SD*			
		AT-362		*Kuruluthuda*	
		Raw	Parboiled	Raw	Parboiled
1	26	0.048±0.014 ^{f}	0.036±0.006^{f}	0.059±0.024^{f}	0.030±0.005^{f}
	30	0.226±0.023^{cd}	0.034±0.016^{f}	0.130±0.030^{e}	0.022±0.012^{f}
	34	0.271±0.017^{bc}	0.035±0.042^{f}	0.199±0.007^{d}	0.039±0.018^{f}
	38	0.427±0.046^{a}	0.032±0.001^{f}	0.300±0.086^{b}	0.053±0.031^{f}
2	26	0.094±0.014^{f}	0.037±0.037^{e}	0.085±0.004^{e}	0.065±0.009^{e}
	30	0.690±0.061^{c}	0.047±0.017^{e}	0.322±0.078^{d}	0.033±0.013^{e}
	34	0.698±0.124^{c}	0.034±0.008^{e}	0.710±0.138^{b}	0.037±0.024^{e}
	38	1.424±0.038^{a}	0.049±0.015^{e}	0.905±0.042^{c}	0.057±0.022^{e}
3	26	0.545±0.195^{e}	0.040±0.010^{f}	0.162±0.050^{f}	0.065±0.019^{f}
	30	0.973±0.014^{cd}	0.047±0.012^{f}	0.861±0.074^{d}	0.053±0.011^{f}
	34	1.133±0.174^{b}	0.034±0.010^{f}	0.863±0.050^{d}	0.055±0.034^{f}
	38	1.714±0.074^{a}	0.043±0.019^{f}	1.061±0.049^{bc}	0.075±0.002^{f}
4	26	0.844±0.230^{d}	0.047±0.012^{f}	0.449±0.235^{e}	0.073±0.016^{f}
	30	1.119±0.075^{c}	0.050±0.021^{f}	0.970±0.082^{cd}	0.064±0.012^{f}
	34	1.570±0.090^{b}	0.040±0.011^{f}	0.952±0.082^{d}	0.071±0.025^{f}
	38	1.957±0.033^{a}	0.062±0.020^{f}	1.810±0.028^{a}	0.083±0.003^{f}
5	26	0.979±0.086^{f}	0.046±0.008^{g}	0.949±0.113^{f}	0.066±0.011^{g}
	30	1.730±0.064^{c}	0.060±0.008^{g}	1.257±0.099^{e}	0.044±0.018^{g}
	34	1.815±0.080^{bc}	0.044±0.010^{g}	1.608±0.166^{d}	0.039±0.011^{g}
	38	2.156±0.026^{a}	0.028±0.012^{g}	1.908±0.057^{b}	0.034±0.007^{g}
6	26	1.465±0.083^{e}	0.051±0.011^{g}	1.193±0.210^{f}	0.051±0.007^{g}
	30	1.743±0.108^{cd}	0.039±0.011^{g}	1.605±0.079^{de}	0.035±0.023^{g}
	34	2.020±0.085^{b}	0.049±0.004^{g}	1.809±0.214^{c}	0.044±0.005^{g}
	38	2.695±0.066^{a}	0.030±0.013^{g}	2.119±0.032^{b}	0.029±0.008^{g}

**Each datum represents the mean of three replicates; Means with the same letter in the same month are not significantly different (Duncan multiple range test at P = 0.05; n = 48)*

TABLE 2:
Storage period of AT-362 and *Kuruluthuda* paddy
in raw form to attain 0.8% DML at different temperature levels

Temperature (ºC)	Maximum allowable storage time (Days)	
	AT- 362	*Kuruluthuda*
26	119	129
30	78	76
34	67	54
38	41	46

The result for correlation analysis between DML of paddy and other storage parameters are presented in Table 3. According to Table 3, a significant correlations of DML only exists with raw paddy as no such correlations were seen in parboiled paddy. The highest correlation coefficient ($r = 0.825$, $P < 0.05$) was identified between DML of raw Kuruluthuda paddy variety and storage time, while the least correlation ($r =0.492$, $P < 0.05$) was found between DML of raw Kuruluthuda paddy variety and storage temperature.

ISSN 2229-5518

TABLE 3

Correlation coefficients of DML of paddy for selected storage parameters

Processing technique	Variety	Correlation Coefficients: DML vs Temperature	DML vs Time
Raw	AT-362	0.53*	0.809*
	Kuruluthuda	0.492*	0.825*
Par	AT-362	-0.095	0.186
	Kuruluthuda	-0.024	0.048

*parameters significant at 0.05 level

Conversely, equations were developed using multiple linear regression to quantify the DML of two paddy varieties in raw form because there were no correlations in DML of parboiled paddy. Based on the results obtained, there is a strong positive correlations ($P=0.000$, $R^2= 0928$) between DML of raw paddy against the 3 variables, stored temperature, storage time, and the variety as shown in Equation 2. Equations 3 and 4 impart the quantification of DML loss of AT-362 variety ($P=0.000$; R2= 0.936) and Kuruluthuda ($P=0.000$; $R^2 = 0.922$) respectively. All obtained regression coefficients of constants and variables in Equations 2, 3 and 4 were significant ($P < 0.05$).

$$DML = - 2.14 - 0.252\ V + 0.0767\ T + 0.320\ S \quad (1)$$

$$DML = - 2.70 + 0.0843\ T + 0.337\ S \quad (2)$$

$$DML = - 2.35 + 0.0692\ T + 0.304\ S \quad (3)$$

T = Storage temperature (ºC); S = Period of storage (months); V = Paddy variety (0 for AT-362 variety, 1 for Kuruluthuda variety)

4. Discussion

The dry mass loss occurs due to the conversion process of accumulated dry matter in paddy grains particularly carbohydrates to carbon dioxide (CO_2), water vapor and energy during grain respiration [21]. The experimental results demonstrated that the variety, the processing technology, and the storage temperature were interactively affected the dry mass loss rate of the paddy in this experiment. That means, the DML depends on the combined effects of levels of all 3 factors rather than that of their individual effects. [22] Seib et al., (1980) found that moisture content, grain temperature, relative humidity, length of the storage time, and the grain type (short and medium) also determine the DML in paddy. Furthermore, they developed an empirical equation to express the relationships of these variables to DML in paddy.

The results clearly indicated that the rate of DML of raw paddy increases with the temperature. Similarly, [17] Navaratne et al. (2013) studied the effects of temperature on DML of paddy, green gram corn and cowpea. They reported that grains stored at higher temperature (>35°C) for 4 months, DML was higher due to the rapid rate of respiration and grains stored at low temperatures, preferably less than 30ºC, the rate of dry mass loss was lower. Furthermore, the present study found that the rate of DML was more than double when storage temperature was increased by 12ºC (26ºC to 38ºC) in both raw paddy varieties during first 3 months of storage. Previous studies support this phenomenon as the corn stored at 10 and 30ºC with 14 to 22% moisture contents, the rate of respiration was doubled for the increment of temperature by 10ºC [16]. Similarly, respiration rate of wheat at 22% moisture, increased from 1 to 12 mg CO_2/(kg·h) when storage temperatures increased from 10 to 40ºC [23]. Conversely, [24] Dillahunty et al. (2000) observed that the rate of respiration increases with the increment of temperature up to certain point and then, it begins to decline. The higher DML in paddy is due to the high metabolism rate of cells with high respiration intensity at high temperatures and reason of decreasing DML even at high temperatures could be due to the vitality and abnormal activities of the enzymes of paddy after being stored for long time. For an instance, DML of Japonica paddy was increasing with temperature until 35ºC while DML at 40ºC was lower than that of 35ºC [15]. Similarly, soluble sugar content which can be predicted as DML of corn stored at 45ºC over a six month period decreased until its moisture content was 20.4% [27]. However, results obtained by this study indicated that DML of AT-362 and Kuruluthuda raw paddy varieties were occurred even up to 38ºC for 6 months. Therefore, viability of paddy grains may not be badly affected by this temperature changes during the period of 6 months of storage.

In more specific terms, the results of the DML of parboiled paddy of both varieties were significantly lower than ($P > 0.05$) the raw paddy at each temperature level in each month. It may be due to destroying and converting the enzymes present in the rice to inactive form as a result of heat applied during steaming in pressure parboiling process [28]. Therefore, most of the biological processes, such as germination, respiration, and another form of biological activities do not occur in parboiled rice. In this study, less DML of parboiled paddy may be strengthened by the fact that their maximum allowable storage time would be more than 6 months. However, no significant difference was found between raw and parboiled paddy on both varieties at 26 ºC during first 2-3 months. This may be due to low DML at low temperatures in raw paddy varieties at the beginning of the storage period, which is close to the DML of parboiled rice [15]

This study indicated that the AT-362 has a higher DML than the Kuruluthuda in raw form during the storage period. This is most probably due to the thickness variation of paddy husk in two paddy varieties. Paddy husk is an excellent insulating material which can prevent the heat flow by conserving energy flow through the gain to loss [29]. [30] Sreenarayanan et al. (1986) were found that paddy husk can be used as a heat resistant material by using transient heat flow method. Furthermore, thermal resistance value can be increased with the thickness of the insulating material [31].This study estimated that thickness of husk in Kuruluthuda (0.2 mm) is higher than AT-362 (0.1 mm). Therefore, Kuruluthuda has a high thermal resistance and as a result of that it may show less dry mass loss compared to the AT-362 stored at same temperature. On the other hand, Kuruluthuda is a traditional paddy variety in Sri Lanka. Most of the traditional varieties selected for breeding program at the national level, are high yielding varieties with resistance to different biotic and abiotic stresses [32]. Previous studies found that Kuruluthuda shows a natural resistance to glyphosate as well [25]. Additionally, gelatinization temperature of this variety was recorded as high compared to other traditional rice varieties in Sri Lanka [33]. Therefore, Kuruluthuda paddy may have a natural resistance to exist at high temperatures without occurring substantial DML.

When the storage temperature is increasing, maximum allowable storage time required to lose 0.8% dry matter in raw paddy is reciprocally decreasing due to increasing respiration rate. Similar effect has reported by [34] Mutters and Thompson (2009), who projected that paddy rice stored at 20ºC, 25ºC, and 30ºC temperatures with 16% initial moisture content would lose 0.5% of its dry matter weight during 13, 5, 1.7 months, respectively. However, similar maximum allowable storage time (40 days) were recorded at 29.5ºC and 35ºC to lose 0.5% dry matter of paddy with 15% of initial moisture content [18]

Analyzed results for correlation for this study found that a significant positive correlation between DML in raw paddy and other storage parameters such as temperature and storage time. The multiple linear regression analysis also found that the influence of storage temperature, time, and paddy variety on the DML was 92.8% for all raw paddy. Therefore, this finding further implies that DML of raw paddy was highly depend on the combined effect of these three factors. Similarly, influence of only storage temperature and time on DML of AT-362 and Kuruluthuda variety were 93.6% and 92.2%, respectively. This high R2 values indicate that these multiple linear regression models can be used to account for wide range of variation in the DML. [22] Seib et al. (1980) developed another equation that can estimate the dry matter loss using grain moisture content, grain temperature, and storage time for medium and long grain varieties.

5 CONCLUSION

To sum up, combination of factors such as the variety, the processing technology, and the storage temperature affect the DML of rough rice (Paddy). This study revealed that DML of raw paddy increased with the increase of temperature within the range of 26°C - 38°C due to respiration. The DML of raw paddy found to be significantly higher at 38oC compared to 26°C during the 6 months period of storage. Further, the rate of DML is nearly doubled when storage temperatures increased from 26°C to 38°C in raw paddy. Maximum allowable storage time of AT-362 and Kuruluthuda were 119 and 129 days at 26°C and 41 and 46 days at 38°C, respectively. The increase in DML in stored raw paddy can be expressed in an equation (DML = - 2.14 - 0.252 V + 0.0767 T + 0.320 S) as a function of variety (V), temperature (T), and storage time (S). Moreover, DML of Kuruluthuda was less than that of AT-362 at each storage temperature during the storage period. It may be due to thick paddy husk and heat resistant behavior of Kuruluthuda paddy variety. Hence, further study have to be carried out to address the heat resistance behavior of Kuruluthuda in more detail. Consequently, heat resistance with low DML varieties can be introduced to farmers for growing. However, DML rate of parboiled paddy appears to be significantly lower than that of raw paddy in both varieties at 30ºC, 34ºC and 38ºC. Therefore, parboiling process and identifying heat resistance paddy varieties can be introduced as an adaptation techniques for global warming in the future in order to suppress DML at high temperatures.

ACKNOWLEDGEMENTS

This work was supported by the Faculty research grant funded by Faculty of Agriculture, university of Ruhuna, Sri Lanka

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