



Short communication

Extreme nighttime air temperatures in 2010 impact rice chalkiness and milling quality

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ABSTRACT

Research shows that elevated nighttime air temperatures (NTATs) contribute to increased chalk formation and reduced milling quality in rice. Arkansas rice-growing regions experienced exceptionally warm weather conditions during the summer of 2010, providing an opportunity to test this hypothesis under extreme conditions. Data from a previous study, conducted in years 2007–2009 (Ambardekar et al., 2011), was extended to include 2010 data, and analyzed to evaluate the correlations of 95th percentiles of NTAT frequencies (NT₉₅) occurring during reproductive (R) stages of six rice cultivars with chalk and peak head rice yields (pHRYs). Long-grain cultivars produced chalk values that were positively correlated to NT₉₅, and pHRYs that were inversely correlated, during the R5 through R8 stages. Medium-grain cultivars, Bengal and Jupiter, which in the original study showed little or no response to elevated NTATs during all R-stages, showed significant positive correlations between chalk, and negative correlations between pHRY, and NT₉₅, during the R7 and R8 stages. The 2007–2009 analyses indicated quadratic relationships of chalk with NT₉₅ and linear relationships of pHRY with NT₉₅. However, addition of the 2010 data indicated that both of these relationships were quadratic in nature. The extreme temperatures observed in 2010 also verified that while cultivars vary in their level of resistance to NTAT effects, all of the rice cultivars analyzed throughout the four-year study exhibited some degree of susceptibility to extreme NTAT temperatures occurring during critical grain-filling stages.

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1. Introduction

Ambardekar et al. (2011) reported the effects of elevated nighttime air temperatures (NTATs) during critical grain-filling stages on chalk formation and milling quality of field-grown rice. This was the first field-scale study of its kind, based on the findings of several previous controlled-environment or historical weather analyses. A landmark study by Peng et al. (2004) showed that NTATs had a more pronounced negative effect than daytime temperatures on field yield of rice, reporting a 10% reduction in rice yield for every 1 °C increase in NTAT and an overall increase in mean NTAT of 1.13 °C from 1992 to 2003. Later studies showed that elevated NTATs, in the range of 21–32 °C, significantly and adversely affected production parameters, including yields (Nagarajan et al., 2010), pollen germination, spikelet sterility, and respiration rates (Mohammed and Tarpley, 2009, 2010), as well as processing parameters, such as peak viscosities (Lisle

et al., 2000), amylose content, and chalk formation (Cooper et al., 2008). Most recently, Fitzgerald and Resurreccion (2009) induced chalk formation by artificially exposing rice plants to 26 °C daily minimum temperature during their grain-filling stages.

The field-scale study by Ambardekar et al. (2011) evaluated two medium- and four long-grain cultivars, grown over three harvest seasons, 2007–2009, and correlated the occurrence of elevated NTATs during various reproductive growth stages (Counce et al., 2000) to chalk formation and head rice yield (HRY). Chalk levels exhibited positive quadratic relationships with the 95th percentiles of NTAT frequencies (NT₉₅) that occurred during the R8, and to a lesser degree, R7, reproductive stages. Head rice yields were linearly and inversely correlated to NT₉₅ during the same stages. The results supported findings of Cooper et al. (2008), in that medium-grain cultivars, Bengal and Jupiter, were less susceptible to the impacts of the NTATs occurring during critical reproductive growth stages than long-grain cultivars, and that within the long-grain cultivars, Cypress was least susceptible to high NTAT.

2010 weather data show that NTATs throughout the Arkansas rice-growing region were exceptionally high, relative to previous years; in many cases, the hottest on record. Anecdotal evidence

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indicated that chalk levels were correspondingly elevated, and milling yields, especially HRYS, were greatly reduced. In light of these claims, the analysis conducted for the original field-scale study was expanded to include 2010 temperature and rice property data. The following is a summary of this analysis, including some notable confirmations and extensions of the outcomes reported previously.

2. Materials and methods

Three long-grain (Cypress, LaGrue, and Wells) and two medium-grain (Bengal and Jupiter) pureline cultivars (Linscombe et al., 1993a,b; Moldenhauer et al., 1994, 2007; Sha et al., 2006), and a long-grain hybrid (XL723) cultivar, were grown as part of the Arkansas Rice Performance Trials, harvested, and prepared according to the methods described in Ambardekar et al. (2011). In 2010, sampling locations, from north to south, included: Keiser (35.7°N), Newport (35.6°N), Pine Tree (35.1°N), Stuttgart (34.5°N), and Rohwer (33.8°N), Arkansas. One modification to the 2007–2009 sampling procedure was that samples were harvested over a narrow range of moisture contents (MCs) in 2010, targeting the optimal harvest MCs (19–22% for long-grain and 22–24% for medium-grain cultivars) described in Siebenmorgen et al. (2007) in an effort to minimize the detrimental effects on HRY of immature kernels occurring at high harvest MCs, and fissuring of kernels at low harvest MCs. While this modified harvest procedure is consistent with the analysis procedure described in the original study, in which the authors selected only those lots harvested within the optimal MC range for determination of “peak” HRY (pHRY), it did slightly reduce the number of samples and harvest MC range from which chalk values were determined.

Temperature data collection, reproductive staging, calculation of Degree-Day-50 (DD50) thermal units, and chalk and peak HRY (pHRY) measurements were conducted in 2010 as described in Ambardekar et al. (2011). Nighttime air temperatures were defined as those occurring between 8:00 p.m. and 6:00 a.m. each day throughout the growing season. Frequencies of the nighttime temperatures that occurred during each R-stage were plotted, and quantile analysis was performed in order to calculate the 95th percentile (NT₉₅), or the temperature below which 95% of all temperatures occurred, for each year/cultivar/location combination.

The data collected in 2010 was added to the original 2007–2009 data set. Subsequent NTAT analyses, including correlations of chalk and pHRY to NT₉₅, were repeated according to the methods of Ambardekar et al. (2011).

3. Results and discussion

Fig. 1 represents an example of NTAT frequencies, which were used to calculate NT₉₅, during the R7 stage of XL723 grown at Stuttgart, AR from 2007 to 2010. This figure illustrates dramatically greater frequencies of NTATs above 26 °C in 2010 than in previous years, which is noteworthy because this is the temperature at which chalk was induced by Fitzgerald and Resurreccion (2009). These greater NTAT frequencies corresponded to greater mean chalk and lower pHRYs, as shown in Fig. 1 inset. Table 1 provides a more comprehensive summary of mean chalk and pHRYs for all cultivars and locations in 2010. Chalk values generally increased while pHRYs decreased from north (Keiser) to south (Rohwer), which was to be expected due to the increasing probability of elevated NTATs from north to south. Comparison to similar data for years 2007–2009 (Ambardekar et al., 2011) shows that chalk values were much greater and pHRYs lower in 2010 than in previous years, especially in the southern locations of Stuttgart and Rohwer.

Table 2 shows correlation coefficients ($\alpha = 0.05$) indicating significant relationships of chalk levels and pHRYs to NT₉₅ occurring during the R5–R8 stages for all cultivars. Generally, correlation coefficients increased with progression through the R-stages, and were greatest in R7 and R8. Significant correlations were observed between chalk levels and NT₉₅ during all R-stages for cultivars LaGrue and XL723, and during R6 through R8 for Cypress, Wells, and Jupiter. Bengal, which had shown no significant correlations between chalk and NT₉₅ at any R-stage in the 2007–2009 study, showed significant correlations in the R7 and R8 stages when 2010 NT₉₅ was included in the analysis.

Correlations of pHRY and NT₉₅ were strengthened with the addition of 2010 data. Medium-grain cultivar, Jupiter, which demonstrated no significant correlations between pHRY and NT₉₅ in the original 2007–2009 study, showed significant correlations in R7 and R8. Medium-grain Bengal, which also showed no correlations based on the 2007–2009 data, produced signifi-

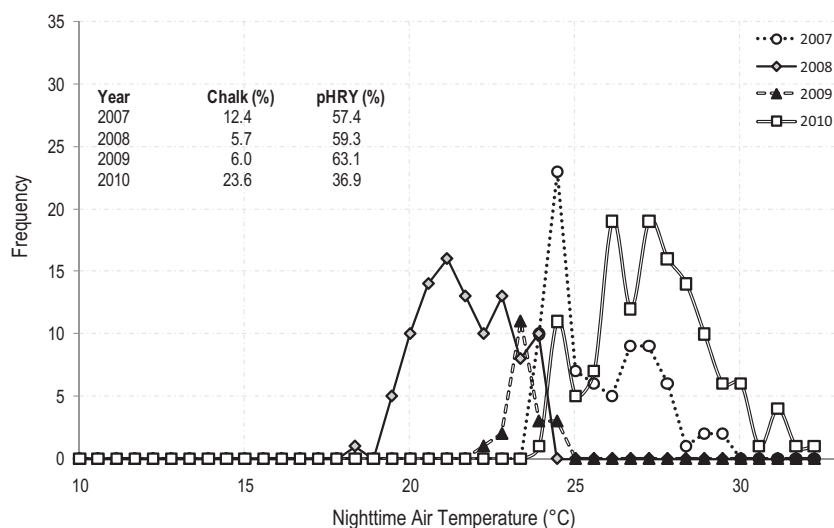


Fig. 1. Nighttime air temperature frequencies during the R7 reproductive stage of long-grain hybrid cultivar XL723 grown at Stuttgart, Arkansas in 2007–2010. Mean peak head rice yields (pHRYs) and chalk levels for each year are indicated (inset).

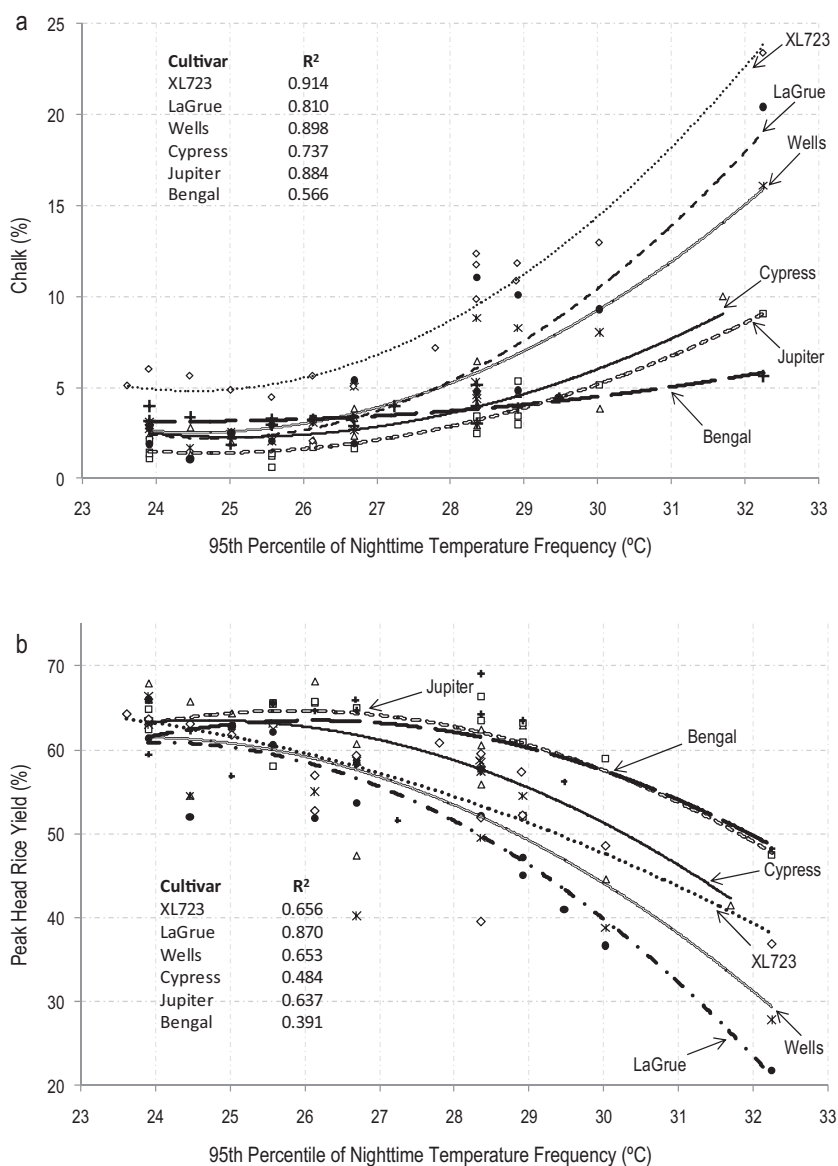


Fig. 2. Relationships of chalk values (a) and peak head rice yields (b) to 95th percentiles of nighttime air temperature frequencies during the R8 stage for the indicated cultivars grown from 2007 to 2010.

Table 1

Chalk values^a and peak head rice yields (pHRYs)^b for cultivars harvested from different locations in 2010.^c

Location ^d	Cultivars											
	Bengal		Jupiter		Cypress		LaGrue		Wells		XL723	
	Chalk (%)	pHRY (%)	Chalk (%)	pHRY (%)	Chalk (%)	pHRY (%)	Chalk (%)	pHRY (%)	Chalk (%)	pHRY (%)	Chalk (%)	pHRY (%)
Keiser	3.96	51.6	2.98	47.4	3.28	52.1	4.46	41.0	5.03	40.3	11.78	39.6
Newport	1.87	56.9	0.61	54.5	1.27	58.1	1.05	52.0	1.66	54.5	2.09	52.8
Pine Tree	3.99	60.4	3.41	55.8	2.87	60.9	4.82	45.0	4.61	49.5	9.88	51.3
Stuttgart	4.40	56.2	5.15	44.6	3.79	59.0	9.28	36.7	8.01	38.8	12.99	48.6
Rohwer	5.61	48.2	9.06	41.5	9.98	47.5	20.41	21.8	16.09	27.8	23.42	36.9
SE	0.37	1.26	0.83	1.42	0.82	1.56	1.82	2.80	1.35	2.52	1.86	1.73

^a Chalk values were measured in duplicate brown rice samples and averaged across all harvest lots for each location/cultivar combination.

^b Head rice yields were measured in duplicate on samples harvested at optimal moisture content and averaged to attain pHRYs. Peak HRYs were adjusted to a 0.4% surface lipid content according to the method of Pereira et al. (2008).

^c Similar data for 2007–2009 is published in Ambardekar et al. (2011).

^d All locations are in AR, USA.

Table 2

Correlation coefficients of chalk and peak head rice yield (pHRY) with the 95th percentiles of nighttime air temperature frequencies (NT₉₅) during the R5 to R8 reproductive stages of long-grain and medium-grain rice cultivars grown in Arkansas from 2007 to 2010.^a

Year	Quality	R-stage	Cultivars					
			Bengal	Jupiter	Cypress	LaGrue	Wells	XL723
2007–2010	Chalk	R5	ns ^b	ns	ns	0.51	ns	0.60
		R6	ns	0.64	0.53	0.70	0.61	0.67
		R7	0.49	0.67	0.68	0.75	0.75	0.73
		R8	0.68	0.75	0.75	0.82	0.86	0.87
2007–2010	pHRY	R5	–0.53	ns	–0.53	–0.71	–0.58	–0.64
		R6	–0.65	ns	–0.80	–0.72	–0.69	–0.60
		R7	–0.58	–0.70	–0.63	–0.87	–0.70	–0.79
		R8	ns	–0.63	–0.69	–0.88	–0.76	–0.82

^a The correlation coefficients presented in this table were calculated using data from 2007 to 2009 that was published in Ambardekar et al. (2011), as well as additional data collected in 2010.

^b Correlation coefficient was not significant.

cant correlations between pHRY and NT₉₅ in the R5 to R7 stages, although the correlation in R8 was not significant.

These results support the hypothesis of Ambardekar et al. (2011), suggesting that elevated NTATs during the grain-filling stage, R6, most prominently impact chalk formation. This hypothesis is based on the concept that the majority of kernels on a given plant lag behind its assigned R-stage, since the classification system is based on the first main-stem kernel observed to reach a particular developmental milestone (Counce et al., 2000). Therefore, a plant classified in the R8 stage will exhibit a great number of less mature kernels that are still in the R6 grain-filling stage.

Fig. 2a and b depicts quadratic relationships between chalk and pHRY, respectively, with NT₉₅ during the R8 stage of all cultivars. Each cultivar produced a positive quadratic relationship between chalk and NT₉₅ (Fig. 2a). The increasing slopes of the relationships for long-grain cultivars, XL723, LaGrue, and Wells, suggest that these cultivars were more susceptible to chalk formation than long-grain cultivar, Cypress, and medium-grain cultivars, Jupiter and Bengal.

Inverse quadratic trends between pHRY and NT₉₅ are shown in Fig. 2b, and again, increasing slopes for long-grain cultivars suggest greater susceptibility to elevated NTATs than medium-grain cultivars. It should be noted that during the R7 and/or R8 stages of the 2007–2009 study, long-grain cultivars demonstrated chalk vs NT₉₅ and pHRY vs NT₉₅ relationships that were linear in nature, and medium-grain cultivars showed no significant correlations between pHRY and NT₉₅. The addition of 2010 data revealed that the relationships for both chalk and pHRY vs NT₉₅ were, in fact, quadratic. These findings suggest that an optimum temperature range may exist for starch formation, below and above which chalk formation is triggered, as described in Ambardekar et al. (2011). Temperature optima are thought to affect the functionality of enzymes responsible for formation of starch in the endosperm during the grain-filling stages (Counce et al., 2005). While these observations support findings that certain cultivars are more susceptible to elevated NTATs than others, they also suggest that optimal temperature ranges may be cultivar-specific and that none of the tested cultivars are completely resistant to extreme conditions like those experienced in 2010.

4. Conclusions

Extreme NTATs experienced in 2010 had a profound effect on the overall milling quality of Arkansas-grown rice. The addition of 2010 data to the original 2007–2009 data set not only strengthens

evidence from controlled-environment research showing that elevated NTATs elicit chalk formation, but also indicates that all of the rice cultivars analyzed throughout the four-year study exhibited some degree of susceptibility to extreme NTATs occurring during specific reproductive stages. Hybrid, long-grain cultivar XL723 was most susceptible to chalk formation, followed by long-grain, pure-line cultivars, LaGrue and Wells. Cypress appeared to be the most resistant long-grain cultivar, while medium-grain cultivars, Bengal and Jupiter, exhibited a high level of resistance, yet incurred significant chalk formation under the extreme conditions experienced in 2010. Likewise, pHRYs were consequently affected by NTATs, with long-grain cultivars incurring greater reductions than medium-grain cultivars. The quadratic nature of the relationship between chalk and NT₉₅ suggests that a temperature optimum may exist, above and below which chalk formation is triggered. However, additional research is needed to fully understand the relationship between NTAT and kernel quality, especially at lower temperature levels.

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