Turkish Journal of Agriculture and Forestry

Volume 40 | Number 1 Article 8

1-1-2016

The effect of trinexapac-ethyl and seeding rate on rice milling yields

İSMAİL SEZER

RASİM ÜNAN

MEVLÜT ŞAHİN

MICHAEL ORRIN WAY

Recommended Citation

SEZER, İSMAİL; ÜNAN, RASİM; ŞAHİN, MEVLÜT; and WAY, MICHAEL ORRIN (2016) "The effect of trinexapac-ethyl and seeding rate on rice milling yields," *Turkish Journal of Agriculture and Forestry*: Vol. 40: No. 1, Article 8. https://doi.org/10.3906/tar-1406-143
Available at: https://journals.tubitak.gov.tr/agriculture/vol40/iss1/8

Turkish Journal of Agriculture and Forestry

http://journals.tubitak.gov.tr/agriculture/

Research Article

Turk J Agric For
(2016) 40: 53-61
© TÜBİTAK
doi:10.3906/tar-1406-143

The effect of trinexapac-ethyl and seeding rate on rice milling yields

İsmail SEZER[1,*], Rasim ÜNAN[2], Mevlüt ŞAHİN[3], Michael Orrin WAY[4]
[1]Department of Field Crops, Faculty of Agriculture, Ondokuz Mayıs University, Kurupelit, Samsun, Turkey
[2]Trakya Agricultural Research Institute, Edirne, Turkey
[3]Central Research Institute for Field Crops, Yenimahalle, Ankara, Turkey
[4]Agricultural Research and Extension Center at Beaumont, Texas A & M University, Beaumont, TX, USA

Received: 25.06.2014 • **Accepted/Published Online:** 04.04.2015 • **Final Version:** 01.01.2016

Abstract: The effects of the plant growth regulator trinexapac-ethyl (TE), conjoined with different seeding rates of rice (*Oryza sativa* L.) milling yields, were evaluated in Turkey between 2009 and 2010. Two rice cultivars (Osmancık-97 and Karadeniz), three seeding rates (400, 500, and 600 seeds m^{-2}), and four doses of TE (0, 100, 200, and 300 g ai ha^{-1}) were compared. The experiments were designed in a randomized block in factorial ordering with 3 replicates. Quality factors including head, cargo, and total rice milling yields, 1000 grain weight, and lodging score were evaluated. Head rice milling yield was affected significantly; however, no statistically significant difference was seen with respect to cargo rice and total milled rice by TE dose. The effect was predicted to depend on grain weight and lodging, which decreased rice milling yield. Seeding rate did not have a significant impact on milling yields. There was a significant correlation between milling yields (head rice and total milled rice but not cargo rice) and both 1000-grain weight and lodging. A seeding rate of 500 seeds m^{-2} was the optimum value among all seeding rates, and the highest milling yields were obtained from Osmancık-97. Irrespective of genotype and seeding rate, treatments with 100, 200, and 300 g TE ai ha^{-1} increased head rice milling yield. All doses of TE reduced 1000 grain weight and lodging. Regression analysis revealed that increasing TE doses raised head rice milling yield.

Key words: Cargo, head rice, lodging, milling, trinexapac-ethyl

1. Introduction

Rice (*Oryza sativa* L.) is one of the most important cereals after maize and wheat, and it serves as a staple food for more than 3.5 billion people of the total world population of approximately 7 billion. Rice plants are cultivated on 163×10^6 ha, and produce 719×10^6 t, with the mean yield about 4.410 t ha^{-1}. It is produced mainly in Asia, particularly China, India, and Indonesia, which supply 65% of the world's rice production. Although paddy rice production has increased in recent years, less attention has been paid to improving productivity both on-farm and in postharvest handling, including milling.

Rice milling yield is one of the primary indices used to quantify the milling quality of rice cultivars. Milling quality aspects affected by temperature resulted in chalkiness, immature kernels, kernel dimensions, fissuring, protein content, amylose content, and amylopectin chain length (Wassmann et al., 2009) Rice breakage during milling causes a significant economic loss, since broken rice often has one-half to one-third the value of whole milled rice. Hence, it is critical from an economic standpoint to maintain milling yield that is as high as possible (Lu and Siebenmorgen, 1995). Several factors can influence the quality of milled rice, which ultimately affects the rough rice market price received by the producer. Some of these factors include milling yield, heat-damaged kernels, red rice, chalkiness, and color (USDA, 2009). Rice milling yield is estimated as the proportional quantities of head rice, total milled rice (whole and broken kernels combined), and rough rice that are produced in the milling of rough rice to a well-milled degree (USDA, 2009). Rice milling yield is directly impacted by factors that can lead to the breakage or fissuring of rice kernels during the milling process. Traditional preharvest factors that have been identified to affect rice milling yield include seeding rate, time of planting, irrigation and N rates, cultivar selection, panicle structure, and harvest moisture content (Gravois and Helms, 1994; Siebenmorgen et al., 2013). Studies evaluating the factors that impact rice milling yield have included cultivar and planting date (Sha and Linscombe, 2007; Sha et al., 2007; Blanche and Linscombe, 2009; Blanche et al., 2009), seeding and fertilization rate (Ottis and Talbert, 2005; Walker et al., 2006; Bond et al., 2008; Harrell and Blanche, 2010), high air temperatures (Liu et

---

* Correspondence: isezer@omu.edu.tr

al., 2013), soil moisture management during the grain-filling period (Zhang et al., 2008), and irrigation water salinity (Zeng and Shannon, 2000).

Establishing an optimum seeding rate is essential for achieving high rice and milling yields. There are difficulties in obtaining the maximum gain in yield in an inadequate and nonuniform rice stand. Most seeding rate research has emphasized optimizing rough rice yield, with little consideration given to head rice or milling yield. Researchers who work on milling yields and seeding rates have found that seeding rates were related to milling yields. Gravois and Helms (1994) reported that grain weight decreased linearly as seeding rate decreased for two rice varieties (Adair and Millie), but grain weight was not affected by seeding rate for two other varieties (Katy and Kaybonnet). The variation in grain weight could account for the lower head rice in Adair and Millie. Conversely, head rice for both Katy and Kaybonnet increased linearly as seeding rate decreased. Researchers reported that head rice should be evaluated on a cultivar basis.

One factor that can significantly impact the milling yield of harvested rough rice is the incidence of crop lodging at harvest time. Lodging in cereal crops has been defined as the state of permanent displacement of the stems from their upright position (Rajkumara, 2008). Adverse weather in the days and weeks just before harvest can cause the rice plants to lodge in the field. The extent of lodging in the field as well as the duration of the lodged crop in the field, along with field conditions and weather during this time, can have a significant impact on the resulting milling quality of the harvested rice crop, in addition to the potential reduction in the amount of yield actually recovered by the harvester in the field (Salassi et al., 2013).

Lodging can vary greatly from year to year or farm to farm; lodging of rice plants is a significant factor to contend with in the production of a rice crop. Relationships among plant characteristics interact with production practices to significantly influence a rice plant's ability to remain standing in the field at crop maturity and be easily harvested, despite high grain yields. The production practices include date of planting, seeding rates, and fertilization rates (Salassi et al., 2013). Application of plant growth regulator is one production practice. Trinexapac-ethyl (TE) is a foliar-absorbed cyclohexanedione plant growth regulator that can inhibit shoot growth in plants. It was registered as a plant growth inhibitor in 1998, and its particular potential in rice cultivation was noted (Fagerness and Penner, 1998). It is an effective plant growth regulator; previous studies show that TE decreases plant height and lodging but increases grain yield (Dunand, 2004; Ünan et al., 2013). The optimal TE dose is predicted to be 170 g ha^{-1} by regression analyses for grain yield in the Karadeniz and Osmancık-97 rice cultivars (Ünan et al., 2013). In this paper, we assessed the effect of seeding rate and TE dose on milling yields (cargo rice, total milled rice, and head rice) of two rice cultivars. The general objective of this study was to estimate the impact of TE and seeding rate on rough rice milling yields. More specifically, the aim of this study was to evaluate the impacts of TE doses and seeding rates on rice milling yields, lodging, and 1000 grain weight, and, using these observed changes in rice milling yield, to estimate the impact of TE and seeding rate on head rice milling yield.

2. Materials and methods

These experiments were conducted in paddy fields of the Black Sea Agricultural Research Institute located in Samsun, Turkey (41°13′27″N, 36°30′08″E) in 2009 and 2010 during the summer season. The soil tests were based on samples taken from the upper layer of soil (20 cm). The soil type was clay, at a neutral pH (pH 7.04). The nutrient values of experimental field were as follows: 19.8 g kg^{-1} organic C, P_2O_5 19.1 mg kg^{-1} Olsen P, and 630.0 mg kg^{-1} extractable K. The research area had a daily average temperature of 20.3 °C, relative humidity of 78.7%, and 399.4 mm of rain during the rice-growing period from May to October in 2009 and 2010.

Two rice (*Oryza sativa* L.) cultivars, Osmancık-97 and Karadeniz, were grown. Osmancık-97 cultivar has a high yield (8.000–10.000 t ha^{-1}), with medium plant length (95–100 cm), and is moderately susceptible to lodging. It is grown throughout Turkey and supplies 80% of the rice production of the country (Sürek, 2009). Karadeniz cultivar has relatively moderate grain yield (6.900–9.000 t ha^{-1}) and high plant length (120–130 cm), and is very susceptible to lodging. Nevertheless, it is preferred for its high grain quality, especially in its grain size; because of this, it is considered an economically attractive cultivar.

Various seeding rates were tested: 400, 500, and 600 seeds m^{-2}. Pregerminated seeds were then sown directly into plots on 20 May in both seasons. Plot size was 12 m^2 (3 m × 4 m). Nitrogen was applied at 40 kg N ha^{-1} in the form of ammonium sulfate (20.5% N) at 3 different growth stages: basal, midtillering, and panicle initiation (Li et al., 2010). Both cultivars were treated with doses of 0, 100, 200, and 300 g TE ai ha^{-1} using a hand-held sprayer. TE was applied twice, at 17 and 7 days before heading, corresponding to Zadoks' growth stages 31–32 (Zadoks et al., 1974).

Lodging severity was scored as a visual percentage ratio of lodged plants at maturity (Growth Stage 71). Lodging was categorized according to a scale of 1–9, where 1 was totally upright and 9 was totally lodged (logging score: 1 = no lodging, 3 = 0%–10% lodging, 5 = 11%–25% lodging, 7 = 26%–50% lodging, 9 = >50% lodging) (TTSM, 2003). Harvest time was determined according to Sürek and Beşer (1998); the harvested area was 10 m^2 (2.7 m × 3.7 m) to remove any edge effects. One-thousand grain weight was weighed out as g from 100 g seed × 8 in each plot, according to ISTA. The sample drying time varied from 2 to 10 days, depending on the initial moisture content of each rice sample. Grain moisture content was measured with a digital moisture meter (DICKEY-John Mini GAC grain moisture meter). The average moisture content of rough rice samples at milling varied from 12.4% to 14.6% for both Karadeniz and Osmancık-97. Three 100-g subsamples from each dried sample were milled. Milling was determined with a lab milling machine (CRM 125 2T Paddy Quality Test Machine, Yaşar Machinery Inc.). Three different milling yields were measured. The first was cargo rice, which had only the brown rice hull removed during 75 s in the lab milling machine; it still retained the bran layers that give it a characteristic tan color and nut-like flavor. The second is total milled rice yield including broken rice, also called white rice or rice after milling, which includes removing all or part of the bran and germ from the brown rice. The third is head rice yield, which is milled rice with length greater than or equal to three-quarters of the average length of the whole kernel (IRRI, 1980).

Data were analyzed using analysis of variance (SAS, 2002) and means of treatment, and were compared based on the least significant difference test (LSD) at a 0.05 probability level. Regression analyses were done using REG procedure as described by the SAS Institute (SAS, 2002). Correlation analyses were conducted using the methods of Snedecor and Cochran (1987); the correlation values among different parameters were calculated from mean values.

3. Results

3.1. Milling yields

3.1.1. Head rice milling yield

Head rice milling percentage is an important factor for quality in the global market. Product price is based on head milling. Head rice milling yield ranged from 49.1% to 61.2% in this study. The analysis of variance revealed highly significant ($P < 0.01$) differences in head rice with each TE application rate and variety. However, there was no significant difference in head rice yield in terms

Table 1. Analysis of variance for plant characters in 2009 and 2010.

Source	DF	Head rice milling yield	Total rice milling yield	Cargo rice milling yield	Lodging	1000 grain weight
Cultivar (C)	1	944.54**	84.89**	21.30**	136.11**	547.76**
Seeding rate (D)	2	21.09	2.22	0.58	3.59**	0.43
TE rates (TE)	3	222.49**	2.04	5.51	211.63**	6.68*
TE-Linear	1	614.87**	3.03	16.00	547.76**	18.77
TE-Quadratic	1	52.44	2.71	0.49	87.11**	0.21
TE-Cubic	1	0.15	0.39	0.02	0.02	1.07
Replication (R)	4	37.85	4.21	2.64	2.06	10.49
C × D	2	19.31	0.28	3.60	0.20	0.12
C × TE	3	15.18	1.57	4.87	46.26**	0.39
D × TE	6	11.58	0.53	1.36	1.44	3.58
C × D × TE	6	7.21	0.58	4.88	0.34	4.25
Years (Y)	1	1330.06**	18.38**	109.55**	28.44**	216.21**
Y × C	1	16.81	2.94	0.61	5.44**	0.13
Y × D	2	6.63	0.31	1.42	0.70	2.23
Y × TE	3	403.75**	2.28	4.58	11.78**	4.96*
Y × C × D	2	17.93	0.67	0.11	1.20	3.45
Y × C × TE	3	16.95	0.69	1.41	3.00**	0.14
Y × D × TE	6	15.29	0.91	4.10	0.25	4.42*
Y × C × D × TE	6	6.59	2.61	1.95	0.97	3.20
Error	92	10.45	1.19	2.60	0.72	1.70
General	143	40.23	2.00	3.60	7.64	7.72

*Significant at the 0.05 probability level; **Significant at the 0.01 probability level.

Table 2. Effect of trinexapac-ethyl and seeding rate on head rice (%).

Variety	Seeding rate (seeds m^{-2})	Trinexapac-ethyl rates (g ai ha^{-1})				
		Control	100	200	300	Mean
	400	55.5	60.5	60.1	61.2	59.3
Osmancık-97	500	56.2	59.3	59.0	61.4	59.0
	600	56.7	57.2	59.5	60.1	58.4
Average		56.1	59.0	59.5	60.9	58.9 A
	400	50.0	53.5	55.2	53.1	53.0
Karadeniz	500	50.1	54.1	57.2	59.2	55.2
	600	49.1	51.8	55.9	56.0	53.2
Mean		49.7	53.1	56.1	56.1	53.8 B
General Average		52.9C	56.1B	57.8A	58.5A	56.3
**	NS†			**		
CV (%)		5.73				

LSD variety = 1.07 ; LSD t-ethyl = 1.51; LSD year = 1.07;
*Significant at the 0.05 probability level.
**Significant at the 0.01 probability level.
†NS, nonsignificant at the 0.05 probability level.

of seeding rate (Table 1). The effects of TE and seeding rate on head rice milling rate are given in Table 2. When evaluated in terms of the rate of TE, the lowest mean head rice percentage observed was 52.9% at the 0-g TE (control) application plot. The highest mean head rice rate observed was 58.5% at the 300-g TE application plot (Table 2). The regression analysis (Figure) showed that TE application had a significantly positive effect ($P < 0.01$) on head rice. A linear relationship existed between the TE application rates and head rice, which was calculated as $y = 53.558 + 0.185x$, where y = head rice milling rate and x = the rate of TE application. The R^2 coefficient was 0.11.

Considering each cultivar individually, mean head rice was 53.8% and 58.9% for Karadeniz and Osmancık-97, respectively, when the results of both years were combined. The means of lowest head rice for Karadeniz and Osmancık-97 were found in the control plots (0 g ai ha^{-1} TE) at 49.7% and 56.1%, respectively. The highest milling rate means for Karadeniz and Osmancık-97 were found to be 56.1% and 60.9% respectively in the 300-g TE application plots. Seeding rate had no significant effect, with mean head rice yields of 56.1%, 57.1%, and 55.8% obtained in fields sown with 400, 500, and 600 seeds m^{-2}, respectively.

3.1.2. Total milling yield

Total milling rice yield (percentage whole milled plus broken kernels) ranged from 67.9% to 70.6% in this study. The analysis of variance revealed significant ($P < 0.01$) differences in total milling with each variety but no effect of TE doses. However, there was no significant difference with seeding rate in terms of total milling yield (Table 1). The effects of TE and seeding rate on total milling rate are given in Table 3. The highest mean total milling yield observed was 69.4% on the 0-g TE application (control) plot (Table 3). Considering each cultivar individually, mean total milling yield was 68.2% and 69.8% in Karadeniz and

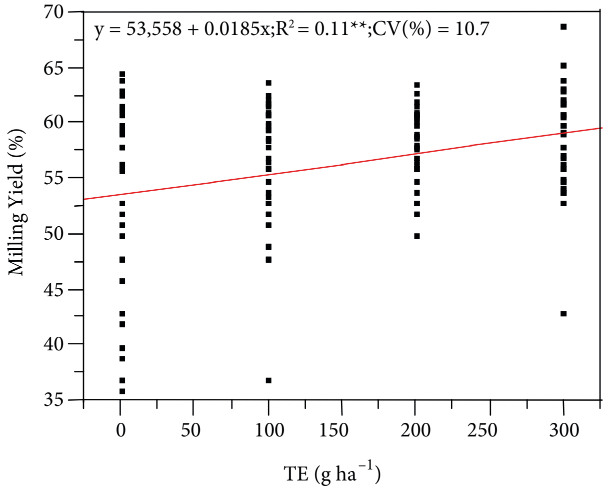

Figure. Regression plot of head rice milling yield against trinexapac-ethyl.

Table 3. Effect of trinexapac-ethyl and seeding rate on total rice milling rate (percentage of whole plus milled broken grains) (%).

Variety	Seeding rate (seeds m^{-2})	Trinexapac-ethyl rates (g ai ha^{-1})				
		Control	100	200	300	Mean
Osmancık-97	400	70.2	70.0	69.4	69.7	69.8
	500	70.6	69.8	69.5	70.3	70.0
	600	70.4	69.7	69.4	69.1	69.6
Average		70.4	69.8	69.4	69.7	69.8 A
Karadeniz	400	68.5	67.6	68.0	68.4	68.1
	500	68.4	68.5	69.0	68.5	68.6
	600	68.5	67.9	68.4	67.9	68.2
Mean		68.5	68.0	68.4	68.3	68.2 B
General average		69.4	68.9	68.9	69.0	69.1
**	NS†			NS†		
CV (%)		1.58				

LSD variety = 0.36.
*Significant at the 0.05 probability level.
**Significant at the 0.01 probability level.
†NS, nonsignificant at the 0.05 probability level.

Osmancık-97 respectively when the results of both years were combined. The means of lowest total milling yields for Karadeniz and Osmancık-97 were found in the control plots (0 g ai ha^{-1} TE) at 49.7% and 56.1%, respectively. The highest total milling yields means for Karadeniz and Osmancık-97 were found to be 56.1% and 60.9% in the 300-g TE application plots, respectively. Seeding rate had no significant effect on total milling yield, with mean total milling yields of 69.0%, 69.3%, and 68.9% obtained in plots sown with 400, 500, and 600 seeds m^{-2}, respectively.

3.1.3. Cargo (brown) rice milling yield

Cargo rice milling yield frequency fluctuated from 74.6% to 77.7% in this research. The analysis of variance produced highly significant ($P < 0.01$) differences in cargo rice milling yield with each variety. However, there was no impact of TE doses and seeding rate on cargo rice milling yield (Table 1).

The effects of TE and seeding rate on cargo rice are given in Table 4. The highest mean cargo rice milling yield observed was 76.6% on the 0-g TE application (control) plot (Table 4). Considering each cultivar individually, cargo rice milling yield was 75.7% and 76.6% for Karadeniz and Osmancık-97, respectively. The highest brown rice milling yields were found in the control plots (75.8% and 77.4% for Karadeniz and Osmancık-97). The lowest cargo rice milling yield means for Karadeniz and Osmancık-97 were found to be 75.2% and 76.3% in the 300-g TE application plots, respectively. Seeding rate had no significant effect on cargo rice milling rates, with mean cargo rice rates of 76.1%, 76.4%, and 76.1% being respectively obtained in fields sown with 400, 500, and 600 seeds m^{-2}.

3.2. 1000 grain weight

The analysis of variance revealed significant differences in 1000 grain weight with TE application rate ($P < 0.05$) and cultivar ($P < 0.01$) (Table 1). Seeding rate and grain weight for rice treated with TE are presented in Table 5. The overall experimental average was 34.8 g. When evaluated in terms of TE dose, it was shown that 1000 grain weight was significantly affected by TE. Thus, 1000 grain weights of cultivars were progressively reduced from the controls to the high doses of TE (0, 100, 200, and 300 TE ha^{-1} have 35.3, 35.0, 34.5, and 34.4 g 1000 grain weights, respectively) (Table 5).

3.3. Lodging

The lodging scores of rice treated with different rates of TE and seeding rate are presented in Table 1. Lodging scores ranged from 1 to 9 with an overall mean of 2.8 (Table 6). Our experimental results indicated that cultivar, TE dose, and seeding rate significantly ($P < 0.01$) affected lodging (Table 1). From the analysis variance, cultivar ×

Table 4. Effect of trinexapac-ethyl and seeding rate on cargo milling yield (%).

Variety	Seeding rate (seeds m^{-2})	Trinexapac-ethyl rates (g ai ha^{-1})				
		Control	100	200	300	Mean
Osmancık-97	400	77.2	77.6	75.9	76.2	76.7
	500	77.7	76.2	76.4	77.3	76.9
	600	77.5	76.2	76.0	75.4	76.3
Average		77.4	76.7	76.1	76.3	76.6 A
Karadeniz	400	75.7	75.1	75.8	75.9	75.6
	500	75.4	77.4	76.1	74.6	75.8
	600	76.4	76.3	76.6	75.1	76.1
Mean		75.8	76.3	76.2	75.2	75.7 B
General average		76.6	76.5	76.1	75.7	76.2
**	NS†			NS†		
CV (%)		2.11				

LSD variety = 0.53
*Significant at the 0.05 probability level.
**Significant at the 0.01 probability level.
†NS, nonsignificant at the 0.05 probability level.

Table 5. Effect of trinexapac-ethyl and seeding rate on 1000 grain weight (g).

Variety	Seeding rate (seeds m^{-2}) Control	Trinexapac-ethyl rates (g ai ha^{-1})				
		100	200	300	Mean	
Osmancık-97	400	33.2	32.3	32.9	33.2	32.9
	500	33.1	32.8	33.6	31.6	32.8
	600	33.2	34.1	31.4	32.6	32.8
Average		33.2	33.1	32.6	32.5	32.8B
Karadeniz	400	37.7	36.7	36.7	36.1	36.8
	500	37.4	37.5	35.8	35.6	36.6
	600	37.0	36.7	36.5	37.2	36.8
Mean		37.4	37.0	36.3	36.3	36.7A
General average		35.3 A	35.0AB	34.5BC	34.4C	34.8
**	*			NS†		
CV (%)			3.73			

LSD variety = 0.4; LSD t-ethyl = 0.6.
*Significant at the 0.05 probability level.
**Significant at the 0.01 probability level.
†NS, nonsignificant at the 0.05 probability level.

Table 6. Effect of trinexapac-ethyl and seeding rate on rice plant lodging score (1–9 lodging scale).

Variety	Seeding rate (seeds m^{-2})	Trinexapac-ethyl rates (g ai ha^{-1})				
	Control	100	200	300	Mean	
Osmancık-97	400	3.0	1.0	1.0	1.0	1.5
500	3.7	2.0	1.0	1.0	1.9	
600	4.7	2.0	1.0	1.0	2.2	
Average		3.8*b*	1.7*c*	1.0*d*	1.0*d*	1.9 B
Karadeniz	400	8.3	3.7	1.3	1.0	3.6
500	8.7	4.7	1.0	1.0	3.8	
600	9.0	4.3	1.7	1.0	4.0	
Mean		8.7*a*	4.2*b*	1.3*cd*	1.0d	3.8 A
General average		6.2A	2.9B	1.2C	1.0C	2.8
**	**			**		
CV (%)			19.68			

LSD variety = 0.28; LSD density = 0.34; LSD t-ethyl = 0.40; LSD variety* t-ethyl = 0.56; lodging score 1 = no lodging, 9 = all lodged.

*Significant at the 0.05 probability level.

**Significant at the 0.01 probability level.

TE interaction was also significant (P < 0.01), but there was no statistically significant interaction between sowing density and TE application (Table 1).

The highest lodging score of 6.2 was obtained in control (0 g ai ha^{-1}) plots. Applying TE decreased lodging score (P < 0.01) to 2.9 (100 g TE ha^{-1}), 1.2 (200 g TE ha^{-1}), and 1 (300 g TE ha^{-1}); thus, increasing the TE application rate reduced the lodging score.

The highest and lowest lodging scores of 3.1 and 2.5 were obtained in 600 and 400 seeds m^{-2} plots. The middle lodging score, 2.9, was observed in 500 seeds m^{-2} plots. There was no statistically significant interaction between sowing density and TE application (Table 1).

3.4. Experimental variable correlations over the growing seasons

Experimental years (Y) had a significant impact on the results of milling rates, grain weight, and lodging. Furthermore, significant (P < 0.01) year (Y) × TE and also Y × cultivar (C) effects were observed. Thus, it was important to attempt to correlate pairs of variables in 2009 and 2010 (Table 7). Over the 2 tested years, the traits that significantly correlated with head rice milling yield at a 0.01 level were lodging, 1000 grain weight, total milling rate, and cargo milling rate. The most important correlation was between head milling rate and cargo milling rate (0.638**). The other important correlation was between lodging and head rice milling rate (–0.512**). This result illustrated that increasing lodging score negatively affected the head rice milling. Increases in 1000 grain weight were associated with reductions in head rice milling yield (–0.316**). Increases in total milling yield were associated with increases in head rice milling yield (0.526**).

4. Discussion

Rice is the staple food of much of humanity; this paper examined a method of militating against a particular constraint on rice milling, for both lodging and grain weight. In this study, milling rates (both cargo rice and total milled rice including broken and head rice), 1000 grain weight, and lodging were evaluated by using 2 rice cultivars (Karadeniz and Osmancık-97), 3 different seeding rates (400, 500, and 600 seeds m^{-2}), and 4 different TE rates (0, 100, 200, and 300 g ai ha^{-1}).

Seeding rate did not significantly affect milling yields (cargo rice, total milled rice, and head rice) and 1000 grain weight for either cultivar, but significantly affected lodging. Our results were supported by the results of some researchers (Ju et al., 1999; Kaçar and Katkat, 2006; Şahin et al., 2009) but other researchers have found significant interactions among seeding rate, grain weight, and milling yield (Gravois and Helms, 1994; Grigg and Siebenmorgen, 2013). These may result from cultivar differences.

Table 7. Correlations among the observed traits (N = 144).

	1000 grain weight	Lodging	Head rice milling yield	Total milling yield
Lodging	0.299**	-	-	-
Head rice milling yield	-0.316**	-0.512**	-	-
Total milling yield	-0.316**	-0.1694*	0.526**	-
Cargo milling yield	0.091	-0.071	0.334**	0.638**

*Significant at the 0.05 probability level.
**Significant at the 0.01 probability level.
†NS, nonsignificant at the 0.05 probability level.

TE application significantly affected head rice milling yield, lodging ($P < 0.01$), and 1000 grain weight ($P < 0.05$). While the lowest head milling rate was 52.9% in control plots, it increased to 58.5% when a TE dose of 300 g was applied. TE application increased head rice milling yield of both cultivars. It was calculated using the derived regression formula that the highest head rice milling yield (59.1%) was achieved with 300 g TE (Figure). TE affected lodging at different doses in different cultivars, as has been discussed in a previous study (Ünan et al., 2013). TE decreased 1000 grain weight for both Osmancık-97 and Karadeniz. TE is a plant growth inhibitor chemical that adversely affects plant length and may negatively affect grain size. Lodging and 1000 grain weight affected milling yields. The inverse relationships were observed among the parameters with milling yields. It was found that the increasing of these traits resulted in decreases in milling yield. It might be the result of more grain broken in the milling process for large-sized kernels and the lodging of damaged kernels. It was found that the seeding rate of 500 seeds m^{-2} was optimum, and the highest head rice milling yield was obtained from Osmancık-97. This may be due to the wide range of cultivars included in different grain types. The TE results obtained in the present study were in agreement with the findings obtained by Im et al. (1993), Han et al. (1999), Ju et al. (1999), Dunand (2004), and Tapley (2008).

The results of this study also showed that lodging had a great impact on head rice yield. Other researchers reported similar results, showing that lodging at the grain-filling stage could cause 9.7% to 15.5% declines in milled rice percentage (Lang et al., 2012). Lodging was found to have a greater impact on head rice milling yield than total grain milling yield. Although market price effects will vary with the general level of average rough rice market prices in a given year, results for the 2011 and 2012 crop years showed market price reductions of $0.0075 to $0.0119 per kg, due to crop lodging impacts on milling yield alone (Salassi et al., 2013). In addition, 1000 grain weight was inversely related to milling and head rice yield. There was a significant correlation between milling yields and both 1000 grain weight ($r = -0.316^{**}$) and lodging ($r = -0512^{**}$).

Our results have demonstrated the potential of TE in preventing lodging in rice, thus increasing milling yields. Results from this 2-year study may provide useful information to the rice milling industry for new crop management tools. This work is intended to foster similar studies using other rice cultivars and to encourage the wide-scale application of TE in rice cultivation. Further research might help improve rice grain quality with TE and other plant growth regulators.

Acknowledgment

The project was supported by the General Directorate of Agricultural Research and Policies, Republic of Turkey Ministry of Food, Agriculture, and Livestock.

References

Blanche SB, Linscombe SD (2009). Stability of rice grain and whole kernel milling yield is affected by cultivar and date of planting. Agron J 101: 522–528.

Blanche SB, Utomo HS, Wenefrida I, Myers GO (2009). Genotype × environment interactions of hybrid and varietal rice cultivars for grain yield and milling quality. Crop Sci 49: 2011–2018.

Bond JA, Walker TW, Ottis BV, Harrell DL (2008). Rice seeding and nitrogen rate effects on yield and yield components of two rice cultivars. Agron J 100: 393–397.

Dunand RT (2004). Trinexapac-ethyl, plant population, nitrogen fertility, and crop production in drill-seeded rice. Proc Pl Growth Reg Soc Am 31: 25.

Fagerness MJ, Penner D (1998). Evolution of V-10029 and trinexapac-ethyl for annual bluegrass sheathed suppression and growth regulation of five cool season turf grass species. Weed Tech 12: 436–440.

Gravois KA, Helms RS (1994). Effect of uneven emergence on rice yield, milling yield, and yield components. Australian J Exp Agr 34: 949.

Grigg BC, Siebenmorgen TJ (2013). Thickness grading impacts on milling and physicochemical properties of long-grain rice. An ASABE Meeting Presentation Paper, Number: 131592878. 21–24 July 2013; Kansas City, Missouri, USA. St. Joseph, MI, USA: American Society of Agricultural and Biological Engineers (doi: http://dx.doi.org/10.13031/aim.20131592878).

Han SW, Park SJ, Cho YC, Lim GJ, Ju YC (1999). Effect of trinexapac-ethyl on lodging-related traits in transplanted rice. Korean J Crop Sci 44: 186–190.

Harrell DL, Blanche SB (2010). Tillage, seeding, and nitrogen rate effects on rice density, yield, and yield components of two rice cultivars. Agron J 102: 592–597.

Im IB, Choi WY, Lee SY, Park KY, Lee JL (1993). Effect of trinexapac-ethyl on growth and lodging of rice. Korean J Weed Sci 13: 19–25.

IRRI (1980). Descriptors for Rice, *Oryza sativa* L., by the IBPGR-IRRI Rice Advisory Committee. Manila, Philippines: International Rice Research Institute.

Ju YC, Park JS, Han SV, Park KY, Rho YD (1999). Effect of growth retardants on lodging-related traits in direct seeded on flooded paddy surface. Korean J Crop Sci 44: 248–252.

Kaçar B, Katkat AV (2006). Plant Nutrition. Nobel Publication No: 849, Science and Biology Series: 29, Ankara (in Turkish).

Lang YZ, Yang XD, Wang M, ZHU QS (2012). Effects of lodging at different filling stages on rice yield and grain quality. Rice Sci 19: 315–319.

Li Y, Yang LZ, Wang C (2010). Evaluation of fertilizing schemes for direct-seeding rice fields in Taihu Lake Basin, China. Turk J Agric For 34: 83–90.

Liu Q, Wu X, Ma J, Li T, Zhou X, Guo T (2013). Effects of high air temperature on rice grain quality and yield under field condition. Agron J 105: 446–454.

Lu R, Siebenmorgen TJ (1995). Correlation of head rice yield to selected physical and mechanical properties of rice kernels. Am Soc Agr Eng 38: 889–894.

Ottis BV, Talbert RE (2005). Rice yield components as affected by cultivar and seeding rate. Agron J 97: 1622–1625.

Rajkumara S (2008). Lodging in cereals: a review. Agric Rev 29: 55–60.

Şahin M, Özcan C, Dok M, Sezer İ, Horuz A (2009). Determination of the amount of suitable nitrogen level and sowing densities in rice. Black Sea Agricultural Research Institute Research Progress and Conclusion Annual Report 2009: 24–48 (in Turkish).

Salassi ME, Deliberto MA, Linscombe SD, Wilson CE, Walker TW, McCauley GN, Blouin DC (2013). Impact of harvest lodging on rough rice milling yield and market price. Agron J 105: 1860–1867.

SAS Institute (2002). SAS User's Guide: Statistics, v. 9.1.3. Cary, NC, USA: SAS Institute.

Sha XY, Linscombe SD (2007). Planting date affects grain and milling yields of water-seeded Clearfield rice. Agron J 99: 1143–1150.

Sha XY, Linscombe SD, Groth DE (2007). Field evaluation of imidazolinone-tolerant Clearfield rice (*Oryza sativa* L.) at nine Louisiana locations. Crop Sci 47: 1177–1185.

Siebenmorgen TJ, Grigg BC, Lanning SB (2013). Impacts of preharvest factors during kernel development on rice quality and functionality. Annual Rev Food Sci Technol 4: 101–115.

Snedecor W, Cochran WG (1987). Statistical Methods. Calcutta: Oxford and IBM.

Sürek H (2009). Rice breeding process in Turkey. 1st National Symposium of Rice Bulletin: 84–99 (in Turkish).

Sürek H, Beşer N (1998). A research to determine the suitable rice (*Oryza sativa* L.) harvesting time. Turk J Agric For 22: 391–394.

Tapley L (2008). Nitrogen fertility and growth regulator effects on hybrid rice yield on clay soil in Texas. Texas Rice Special Section–Highlighting Research in 2008: 9–10.

TTSM (2003). Foundation of Seed Registration and Certification. Technical Instructions of Experiment Measuring Agricultural Values for Rice. Ankara, Turkey: TTSM (in Turkish).

Ünan R, Sezer İ, Sahin M, Mur LAJ (2013). Control of lodging and reduction in plant length in rice (*Oryza sativa* L.) with the treatment of trinexapac-ethyl and sowing density. Turk J Agric For 37: 257–264.

USDA (2009). United States Standards for Rice. Washington, DC, USA: Federal Grain Inspection Service.

Walker TW, Martin SW, Gerard PD (2006). Grain yield and milling quality response to two rice cultivars to top-dress nitrogen application timings. Agron J 98:1495–1500.

Wassmann R, Jagadish SVK, Heuer S, Ismail A, Redona E (2009). Climate change affecting rice production: the physiological and agronomic basis for possible adaptation strategies. Adv Agron 101: 59–122.

Zadoks JC, Chang TT, Konzak CF (1974). A decimal code for the growth stages of cereals. Weed Research 14: 415–421.

Zeng L, Shannon MC (2000). Effects of salinity on grain yield and yield components of rice at different seeding densities. Agron J 92: 418–423.

Zhang H, Zhang S, Yang J, Zhang J, Wang Z (2008). Postanthesis moderate wetting drying improves both quality and quantity of rice yield. Agron J 100: 726–734.