DETERMINATION OF DOCKAGE FOR ACCURATE ROUGH RICE QUALITY ASSESSMENT

G. G. Atungulu, B. Prakash, X. Wang, T. Wang, R. Fu, R. Khir, Z. Pan

ABSTRACT. *Determination of dockage of freshly harvested rice is crucial for precise development of a universal rice shrink chart. The objectives of this research were to determine the effect of different factors, including rice variety, farm location, harvest moisture and time, drying, dropping, weather events such as wind and rainfall, and type of harvester, on dockage. The study was conducted during two consecutive rice harvesting seasons. The dockage of freshly harvested rice with moisture content (MC) ranging from 18% to 27% wet basis (w.b.) varied between 0.2% and 2.0% with averages of 0.92% and 0.79% in 2010 and 2011 harvest seasons, respectively. The corresponding averages of dockage of dried rice with MC of 14±1% (w.b.) were 0.78% and 0.65%, which were lower than those of freshly harvested rice. There were no significant differences (p>0.05) in dockage among the studied rice varieties. It was also observed that dockage was not significantly affected (p>0.05) by the harvest MC, geographical location and dropping from certain height. However, wind and rainfall events significantly (p<0.05) increased the dockage. The results also revealed that the type of harvester affected the dockage. The obtained dockage results for all tested factors were significantly (p<0.05) lower than 2% which is the value accepted in the rice industry at present.*

Keywords. *Rice, Shrink chart, Dockage.*

Although freshly harvested rough rice is weighed when received at the dryers, the paid final weight of dried rice in the rice industry is affected by dockage and invisible and moisture losses caused by handling and drying processes. Dockage is defined as the proportion of materials other than grains in the harvested rice and is commonly expressed as a percentage. Dockage is typically assumed at 2% level of harvested rice at dryers (Mutters and Thompson, 2009). However, the assumed dockage number was established over four decades ago and is likely overtaken by recent advances in harvesting and handling technologies, as well as changes in weather conditions. Therefore, it is vital to precisely determine dockage percentage and factors that affect it because even 1% error means significant economic consequences to rice growers.

Submitted for review in August 2012 as manuscript number FPE 9887; approved for publication by the Food & Process Engineering Institute Division of ASABE in January 2013.

The authors are **Griffiths G. Atungulu, ASABE Member,** Associate Project Engineer, **Bhagwati Prakash, ASABE Member,** Graduate Student, **Xiaotuo Wang,** Visiting Scholar, **Tianxin Wang,** Visiting Scholar, **Ruipeng Fu,** Visiting Scholar, Department of Biological and Agricultural Engineering, University of California-Davis, Davis, California USA; **Ragab Khir,** Post-doctoral Scholar, Department of Biological and Agricultural Engineering, University of California-Davis, Davis, California USA and Department of Agricultural Engineering, Faculty of Agriculture, Suez Canal University, Ismalia, Egypt; and **Zhongli Pan, ASABE Member,** Research Engineer, Adjunct Professor, Processed Foods Research Unit, USDA-ARS-WRRC, Albany, California USA and Department of Biological and Agricultural Engineering, University of California-Davis, Davis, California USA. **Corresponding author:** Zhongli Pan, Department of Biological and Agricultural Engineering, University of California-Davis One Shields Avenue, Davis, CA 95616, USA; phone: 510-559-5861; e-mail: zhongli.pan@ars.usda.gov or zlpan@ucdavis.edu.

In the rice industry, shrink factors are normally used by grain dryers to calculate the final dried rice weight. The overall shrink factors account for the reduction in weight due to moisture lost in drying, dockage removal during cleaning and handling operations, and invisible losses. The overall shrink factor S (%), is defined by the following formula:

$$S = \frac{W_i - W_f}{W_i} \times 100 \quad (1)$$

where W_i (lb) is the weight of rough rice received at dryers and W_f (lb) is corresponding dried rough rice weight. Therefore, if the overall shrink factor is known dried rough rice weight can be easily determined using the following relationship:

$$W_f = W_i - W_i \times \frac{S}{100} = W_i \left(1 - \frac{S}{100}\right) \quad (2)$$

The shrinkage of rice due to moisture ($S_{m,}$ %) loss on drying can be calculated based on the initial and final moisture contents of rice. Therefore, the overall shrink factor can be expressed as follows:

$$S = \left(d + k + S_m\right) \quad (3)$$

where d is dockage (%) and k is invisible loss (%). Invisible losses are due to unknown sources and are harder to determine accurately. Typically, rice drying facilities set value of invisible loss in the range of 1.5% to 3.5%.

A comprehensive study of factors influencing rice dockage is essential to provide guidelines to the rice industry on how to update shrink chart. At present, harvesters and handling equipment have, from technological viewpoint, greatly improved and dockage might be significantly lower. Over the past few years, modern rice harvesters or combines with different feeding, cutting, threshing, separation, and cleaning mechanisms have emerged (Andrews et al., 1993a; Andrews, 1993b; Bennett et al., 1993). A significant advance in the design of combines was the rotary design. To harvest rice, growers use different types of configurations of harvester headers including conventional and stripper headers. The stripper headers have flexible fingers that detach kernels by flailing through standing rice. Rice panicles are combed through large, keyhole-shaped openings, leaving the rice plant nearly intact while the grain flips into the header. On the other hand, the conventional header cuts the whole rice stalk and feeds it into the combine where the threshing, cleaning, and separation finally take place. The harvester model and header combinations chosen for rice harvesting may have an impact on rice dockage (Wilson, 2001). In addition, rice harvesting seasons are generally characterized by irregular weather events like rainfall, fog, strong winds, and wind gusts of different patterns and magnitudes. The repercussions of these events typically include changes in rice moisture and posture which have impact on harvester operations and performances (Siebenmorgen et al., 1992; Andrews, 1993b). Timing of the rice harvesting in relation to the onset of the aforementioned weather events could be crucial to reduce rice dockage. Typically, most growers delay harvesting of rice for a few days after rains to allow rice moisture to reduce to acceptable levels for harvesting. Also, there is a growing concern over incidences of strong north winds and their negative impacts on rice dockage and quality in California. In order to update the shrink chart currently used in the industry, it is important to understand the impact of the aforementioned factors as well as that of rice variety and growing location on rice dockage. Based on our literature review, there is no documented research related to the effect of these factors on rice dockage.

The ultimate aim of this research was to investigate factors affecting rice dockage for providing suitable recommendations to update rice shrink chart. The specific objectives were: (1) to determine dockage of different varieties of rice harvested at different harvest moistures and collected from different rice growing regions; (2) to study the impact of drying on rice dockage; (3) to investigate the impact of dropping rice from different elevations on dockage; (4) to determine the impact of type of rice harvester on dockage; (5) to investigate the impact of weather events such as winds and rainfall on dockage of rice; and (6) to provide recommendations to the rice industry for updating shrink chart.

Material and Methods

Samples

Freshly harvested medium grain rice samples, varieties (M104, M202, M205, and M206) with harvest moisture ranging from 14% to 27% (w.b.), were used for conducting this study. The research was conducted in two consecutive rice harvesting seasons of 2010 and 2011. In the 2010 rice harvesting season, rice samples were collected weekly from three drying facilities located in Colusa, Butte, and Yolo counties in California. These three facilities were selected in order to obtain samples from majority of rice growing areas in California and determine if geographical differences affect dockage of rice samples. Each week, 3 to 5 samples were collected from each facility. Each of these rice samples was grown by different farmers. Total number of rice samples used in the 2010 rice harvesting season was 51. Out of the 51 collected rice samples, 3 were M104, 6 were M202, 19 were M205, and 23 were of M206 variety. In 2011 rice harvesting season, rice samples were procured from Farmers' Rice Cooperative (West Sacramento, Calif.) and from specific rice farms and harvesters in Arbuckle and Grimes, California. The samples obtained from the Farmers' Rice Cooperative (FRC) were used to study the effect of seasonal changes and to confirm repeatability of results obtained in the previous year's research. During the 2011 rice harvesting season, samples were collected weekly from each harvester for up to seven weeks. Total number of rice samples collected in the 2011 rice harvesting season was 50. For both seasons, each rice sample was divided into two portions. One portion was dried while the other remained at harvest moisture. For each sample portion, dockage was measured. Three replicates were conducted for each rice sample in all experiments.

Dockage Test and Drying Experiments

Dockage tester (Carter-Day XT-1 dockage tester, Minneapolis, Minn.) was used to mechanically separate various components of rice sample namely grains, chaff, and other foreign materials according to their particle size. Standard procedures prescribed by the USDA Federal Grain Inspection Service (FGIS) (1997) were followed to determine the dockage. Based on the standard procedures for medium grain rice, sieve number 31 in top and 27 in bottom sieve carriages were used.

In each test, 1000 g (2.2 lb) of rough rice sample were used. After the test, three fractions which were separated based on size: chaff and larger non-grain items (top collector), grains (middle collector) and fine particles including dust (bottom collector) were obtained. For convenience of explanation, the fractions are described in this paper as larger materials, grains and fine materials, respectively. Dockage was described in percentage and calculated as follows (eq. 5):

$$D = 100 \times \frac{(W_l + W_f)}{W_r} \quad (5)$$

where D is dockage (%), W_l is weight of larger materials (g), W_f is weight of fine materials (g), and W_r is weight of rice sample (g).

Moisture content of each of the three fractions was determined after dockage testing using hot air oven method (130°C for 19 h) (*ASABE Standards,* 2006). *ASABE Standards* (2006) recommend the standard parameters for oven method of moisture measurement of unground grain and seeds. For wheat, the recommended sample size is 10 g, oven temperature is 130°C, and heating time is 19 h. However, for moisture measurement of rice, there is no recommendation of sample size, oven temperature, or heating time. Therefore, in this study, moisture content of rice was determined by adopting the ASABE standards guidelines for wheat. Heating time of 19 h was found sufficient because using longer heating periods did not provide higher accuracy in the moisture measurement.

Harvested rice was dried by slow ambient air drying (25°C) to about 14±1% moisture (wet basis) in lab-scale box-shaped column dryer developed at the food processing laboratory at the University of California in Davis. Moisture of different rice fractions was measured by either a commercial Dickey-john moisture meter (Auburn, Ill.) or the aforementioned hot air oven method.

Dropping Experiments

During post-harvest handling operations such as drying and storage, rough rice is dropped from some height. This dropping may affect its dockage. To determine such impact on dockage quantitatively, 1000 g of rice samples were dropped from a 15 ft height multiple times (one to five times) and dockage was measured. In the experiments, rice samples were dropped once and five times, separately.

Harvesters

Working with rice growers and Rice Experiment Station in California, popular models of rice harvesters with different harvester headers were identified in order to investigate the impact of harvesters on dockage. Four harvesters, including John Deere model mounted with stripper header, Case with conventional header, John Deere with conventional header, and Claas Lexion with conventional header were selected to harvest rice used in this study (figs. 1 and 2).

(a) (b)

Figure 1. Rice harvesters of (a) Case (1999) and (b) John Deere (2007) models mounted with conventional headers.

(a) (b)

Figure 2. Rice harvester of John Deere (2011) model mounted with a stripper header (a) and magnification of the stripping knife section (b). .

Rice Sampling during Strong Winds and Rainfall Event

During rice harvesting seasons, weather event such as rainfall, wind gust, speed, and direction occur in different patterns and magnitudes. Weather conditions during the 2011 rice harvesting season were monitored to determine specific days with notable magnitudes of rainfall and strong winds. Rice samples were collected for 3 and 4 days continuously after the onset of strong wind and major rainfall events, respectively. The collected rice sample was harvested with Claas Lexion with conventional header. Dockage tests for freshly harvested and dried rice samples were conducted as described before and results were compared with those at normal weather conditions. Table 1 summarizes days of rice sample collection and corresponding magnitudes of weather events during the sampling duration.

Statistical Analysis

All data represents average of at least three replicates. Statistical analysis was conducted to establish ANOVA tables and multiple comparisons of significant differences at 0.05 level among data using SPSS software (SPSS Inc., Chicago, Ill.).

Results and Discussion

Dockage of Freshly Harvested and Dried Rice Samples

Impact of Harvest Location, Rice Variety and Harvest Moisture Content

Based on study findings, location of rice harvest did not have any significant impact on dockage (table 2).The rice variety M205 was not available for inclusion in the 2011 studies. In general, there was no significant effect of rice variety on dockage. The dockage of freshly harvested rice (obtained at dryers) with moisture content (MC) of 18% to 27% wet basis (w.b.) varied between 0.2% and 2.0% with averages of 0.92% and 0.79% in 2010 and 2011 harvest seasons, respectively (table 3). The corresponding mean values of dockage of dried rice with MC of 14±1% (w.b.) were 0.78% and 0.65% which were lower than those of freshly harvested rice. Averages of dockage of freshly harvested and dried samples for the two rice harvesting seasons, 2010 and 2011, were statistically different ($p<0.05$). However, dockage values of freshly harvested and dried samples between the seasons were not significantly different ($p>0.05$). Rice dockage in 2011 was slightly lower than 2010, although not significantly ($p>0.05$). The obtained results revealed that dockage of rice were significantly lower than the currently assumed 2% weight of the freshly harvested rice.

Table 2. Dockage of rice samples from different harvesting locations in California.

Dryer Location, County	Number of Samples	Dockage (%)[a]
Colusa	17	0.7 ±0.4a
Butte	17	0.8 ±0.5a
Yolo	17	1.1 ±0.6a

[a] Means with different letters in each column for each category are significantly different at $p < 0.05$ level.

In freshly harvested rice samples, larger materials (composed mainly of chaff) have highest moisture while the finer materials have the lowest moisture among all the three dockage fractions. For example, in first week rice samples, average moisture (wet basis) of larger materials, grains and fine materials were 32.8%, 24.1% and 23.4%, respectively. During drying, these fractions of rice undergo different amount of moisture loss. After drying, average moisture (wet basis) of larger materials, grains and fine materials were 14.7%, 14.9%, and 13.8%, respectively. Due to highest moisture loss in larger materials, dockage of dried rice samples decreased slightly in most rice samples.

Drying of the rice caused no significant difference ($p>0.05$) to the proportion of individual dockage fractions generated, either large or fine dockage. However, proportions of large and fine fractions were significantly different for both freshly harvested and dried rice as illustrated by ANOVA of the data (table 4). In commercial drying operations, large fraction of chaff and other non-grain materials are typically removed before drying by pneumatic cleaning. This saves a large amount of heat energy that otherwise would have been needed to dry these materials. This separation of non-grain materials before drying lowers the dockage of dried rice enormously. In this study, such air-separation was not conducted and hence the lowering of dockage reported here is purely due to differential change in moisture of different fraction during drying.

Table 1. Time of sample collection and magnitudes of weather events.

Weather Event	Sampling Number	Date (m/d/y)	Temperature (°F)	Wind Speed (mph)	Precipitation (in.)	Remarks
Wind	1	10/30/2011	64	6	0	
	[a]	11/1/2011	64	28	0	Onset of strong winds
	2	11/2/2011	60	17	0	
	3	11/3/2011	54	16	0.11	Rainy
	4	11/4/2011	46	9	0	
Rainfall		11/5/2011	44	17	0.38	Onset of strong rains
		11/6/2011	49	9	0.16	Rainy
		11/7/2011	48	6	0	Foggy
	1	11/8/2011	47	6	0	
	2	11/9/2011	49	5	0	Foggy
	[a]	11/10/2011	51	7	0	
	3	11/11/2011	50	8	0.12	Rainy

[a] Indicate that harvesters were unable to operate due to bad weather events.

Table 3. Dockage of freshly harvested and dried rice of different varieties procured in 2010 and 2011 rice harvesting seasons.

Rice Variety	Rice Dockage			
	Freshly Harvested 2010	Freshly Harvested 2011	Dried 2010	Dried 2011
M104	1.0 ±0.6	0.65 ±0.04	0.93 ±0.54	0.46 ±0.08
M202	0.9 ±0.5	0.85 ±0.10	0.84 ±0.37	0.74 ±0.05
M205	0.6 ±0.4	ND	0.50 ±0.31	ND
M206	1.1 ±0.5	0.88 ±0.05	0.83 ±0.52	0.74 ±0.02
Mean[a]	0.92 ±0.23a	0.79 ±0.13a	0.78 ±0.19b	0.65 ±0.16b

[a] Means with different letters in each row for each category are significantly different at p < 0.05 level.

Table 4. Analysis of fine and large fractions of dockage of freshly harvested and dried rice samples.

	Sum of Squares	Degrees of Freedom	Mean Square	p value
ANOVA for Freshly Harvested and Dried Samples				
Between groups	0.0167	1	0.017	p > 0.05
Within groups	2.1461	66	0.033	
Total	2.1628	67		
ANOVA for Fine and Large Fractions of Freshly Harvested and Dried Samples				
Between groups	0.958	3	0.3193	p < 0.05
Within groups	1.205	64	0.0188	
Total	2.163	67		

Based on results, no definite trend was observed between dockage and harvest moisture (fig. 3). It is important to note that each data point in figure 3 represents an average of triplicate data for rice dockage and could be at rain, wind, or regular weather event. The information to communicate from the figure is the range of moisture and dockage in samples of rice harvested during the two consecutive seasons. Because the data points consist of samples from all the three weather events, a wide variation in dockage values can be observed. It was noted that dockage of rice samples harvested at higher moisture (>25%) was generally high in 2010 compared with 2011. As it will be discussed later in this section, weather effects among other factors were added as constrains for experiments conducted in 2011 for better dockage estimation. Because weather events have impact on rice moisture the dockage for specific weather event duration may reflect narrowed down moisture range of the sample and provide a price value for dockage.

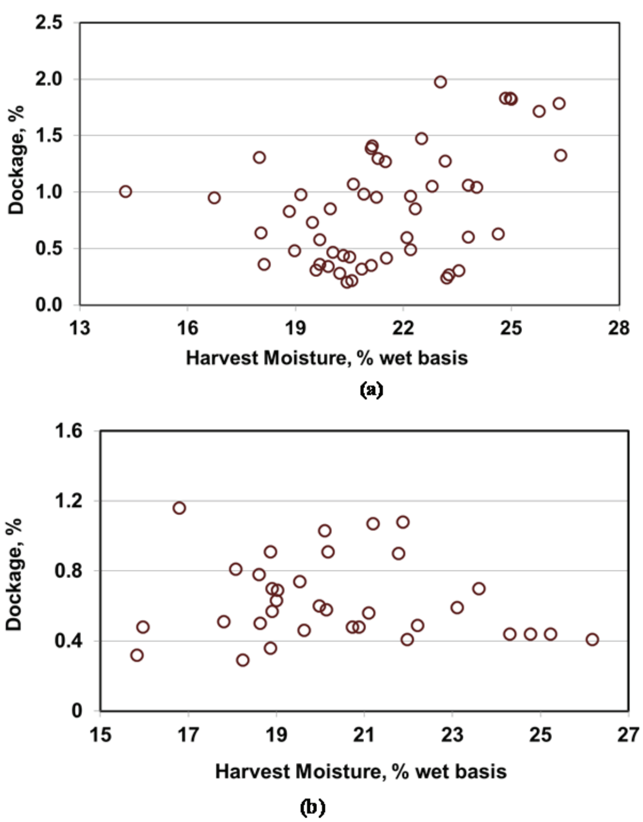


Figure 3. Dockage vs. harvest moisture of freshly harvested rice samples in (a) 2010 and (b) 2011 rice harvesting seasons.

IMPACT OF DROPPING RICE ON DOCKAGE

Rice samples weighing 1000 g were dropped one and five times from a 15-ft height. Three categories of rice samples with different initial dockage levels of freshly harvested and dried rice were used in the tests. There was no significant difference (p>0.05) between dropping the rice one or five times for freshly harvested samples. However, dropping dried samples caused some slight increase in dockage. In general, dockage of dropped freshly harvested samples was found to be slightly higher (0.03% more) than that of samples that did not undergo dropping tests (table 5). Some fragile fractions of material in the rice broke after the free fall. This resulted in a change in proportions of different fractions of dockage in the samples and thus affected overall dockage. Among the different fractions, the amount of larger materials and grains decreased while the amount of fine materials increased. Since the change in dockage was very small, from the second week of harvest onwards, the dropping test was performed for only two rice samples each week.

IMPACT OF HARVESTER TYPE ON RICE DOCKAGE

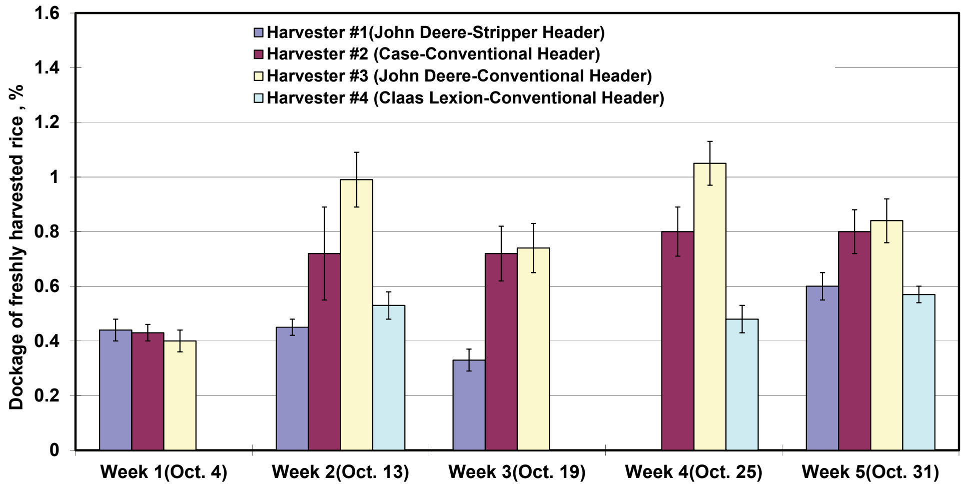
The type of harvester and header combination influenced the magnitude of rice dockage for both freshly harvested and dried rice as shown in figure 4. The lowest average dockage (0.5%) occurred in the case of harvester equipped with stripper header compared to conventional header (up to 1%).

Dockages of both freshly havested and dried rice samples which had been harvested with the following harvester and header combinations were statistically different (p<0.05): John Deere with stripper header, Case with conventional header, and John Deere with conventional header. However, no significant difference (p>0.05) was observed between dockage of rice harvested with John Deere with stripper header and that harvested with Claas Lexion with conventional header. It was clear that besides the impact of harvester model, dockage was also significantly different within different header configurations. The statistical analysis revealed that the

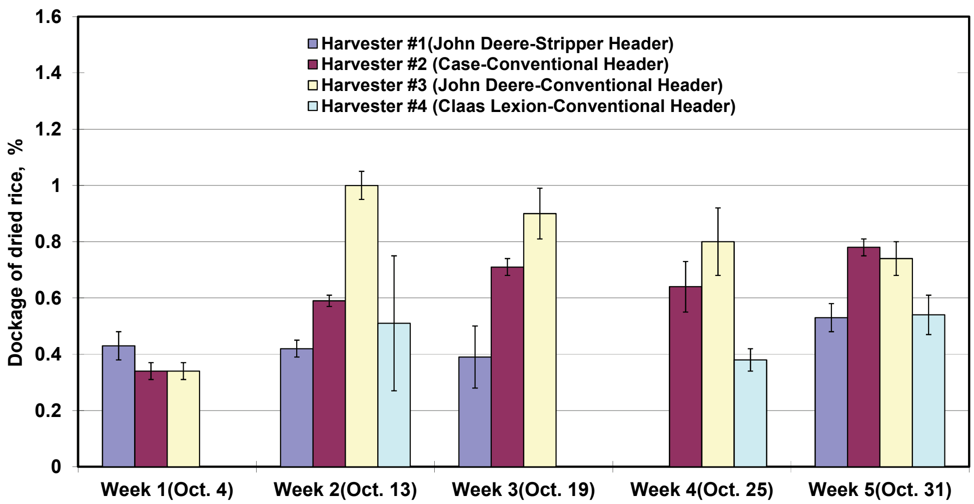
Table 5. Effect of dropping on dockage of freshly harvested and dried rice in 2010 harvest season.

Sample Category	Dockage[a]					
	Freshly Harvested			Dried Sample		
	No drop	1 drop	5 drops	No drop	1 drop	5 drops
1	1.19 ±0.19a	1.42 ±0.23b	1.36 ±0.16b	0.54 ±0.19c		
2	0.29 ±0.03a	0.30 ±0.07b	0.30 ±0.06b	0.28 ±0.04c	0.23 ±0.01d	0.27 ±0.00c
3	0.45 ±0.20a	0.48 ±0.21a	0.46 ±0.17a	0.42 ±0.11c	0.40 ±0.09d	0.41 ±0.23c

[a] Means with different small letters in each row for each sample category are significantly different at p < 0.05 level.



(a)



(b)

Figure 4. Impact of harvester and header type on (a) dockage of freshly harvested rice and (b) dried rice samples.

dockages of both freshly harvested and dried rice samples were significantly different ($p<0.05$) when the impact of John Deere with stripper header and John Deere with conventional header were compared. The reasons for low dockage with stripper headers were that they combed rice out of the rice head and left whole stalks still standing unlike the conventional header which gathered the stalks plus any other chaff, making separation and cleaning more demanding and thereby creating more dockage. It is worth mentioning that header dimensional aspects, age as well as cutting, feeding, threshing, separating, and internal cleaning mechanisms of harvesters, which are unique to each set of harvester and header, may also affect the dockage. Regardless of the type of harvester used, dried rice samples had less dockage compared to that of freshly harvested rice. It was also noted that at the onset of harvest, in particular week one, dockage was significantly different ($p<0.05$) than the rest of the weeks.

Based on average dockage results of freshly harvested and dried rice for the entire 2011 rice harvesting season and the combination of harvester and headers tested, John Deere with stripper header had better performance followed by Claas Lexion with conventional header, Case with conventional header, and finally John Deere with conventional header (table 6).

It should be noted that the average dockage of rice obtained at the drying sites could be slightly higher compared to dockage values obtained when rice was obtained directly at the farm from growers using specific harvesters. The reason for this is that during harvesting operations in the field most growers loaded bankers with rice from different harvesters and the rice that was finally delivered to the drying sites by trucks came from varied harvesters. For the studied seasons, the average dockage values for rice obtained from drying sites (0.9% and 0.7%) were higher than those obtained directly from growers (0.4% and 0.5% in case of John Deere harvester with stripper header) for both freshly harvested and dried rice samples, respectively.

Analyzed results related to the proportions of large and fine fractions of dockage in freshly harvested (raw) and dried rice resulting from using the studied harvesters are shown in figure 5. All the harvesters produced more large fraction of dockage than the fines. The proportion of large fractions of dockage was least in case of rice harvested with the stripper header. Based on statistical analysis of variance (ANOVA), it was observed that the type of harvester significantly ($p<0.05$) influenced the proportion of fine and large fractions of dockage generated. The proportions of large and fine fraction contained in dockage did not significantly change with the harvest season ($p>0.05$).

Impact of Weather Events on Rice Dockage

Rice dockage was affected by strong wind and rainfall events as indicated in table 7. Dockage was higher on windy (0.9%) and rainy (2%) days compared to during normal weather conditions (0.5%). It was also noted that fluctuations of rice moisture occurred due to strong winds and rains. At the onset of strong winds, the harvested rice moisture content dropped. On the contrary, moisture contents of rice increased significantly due to rain. It is believed that because strong wind and rain may cause rice to droop or fall down, the harvesting operation is negatively influenced. Especially, rice cutting and feeding efficiency

Table 6. Average dockage of freshly harvested and dried rice from different harvesters.[a]

Sample Type	John Deere with Stripper Header	Case with Conventional Header	John Deere with Conventional Header	Claas Lexion with Conventional Header
Dried	0.44 ±0.06Aa	0.61 ±0.17Ba	0.76 ±0.25aC	0.48 ±0.09Aa
Freshly harvested	0.46 ±0.11Ab	0.70 ±0.15Bb	0.80 ±0.26Cb	0.53 ±0.05Ab

[a] Means with different capital and small letters in each row and column of each category are significantly different at $p < 0.05$

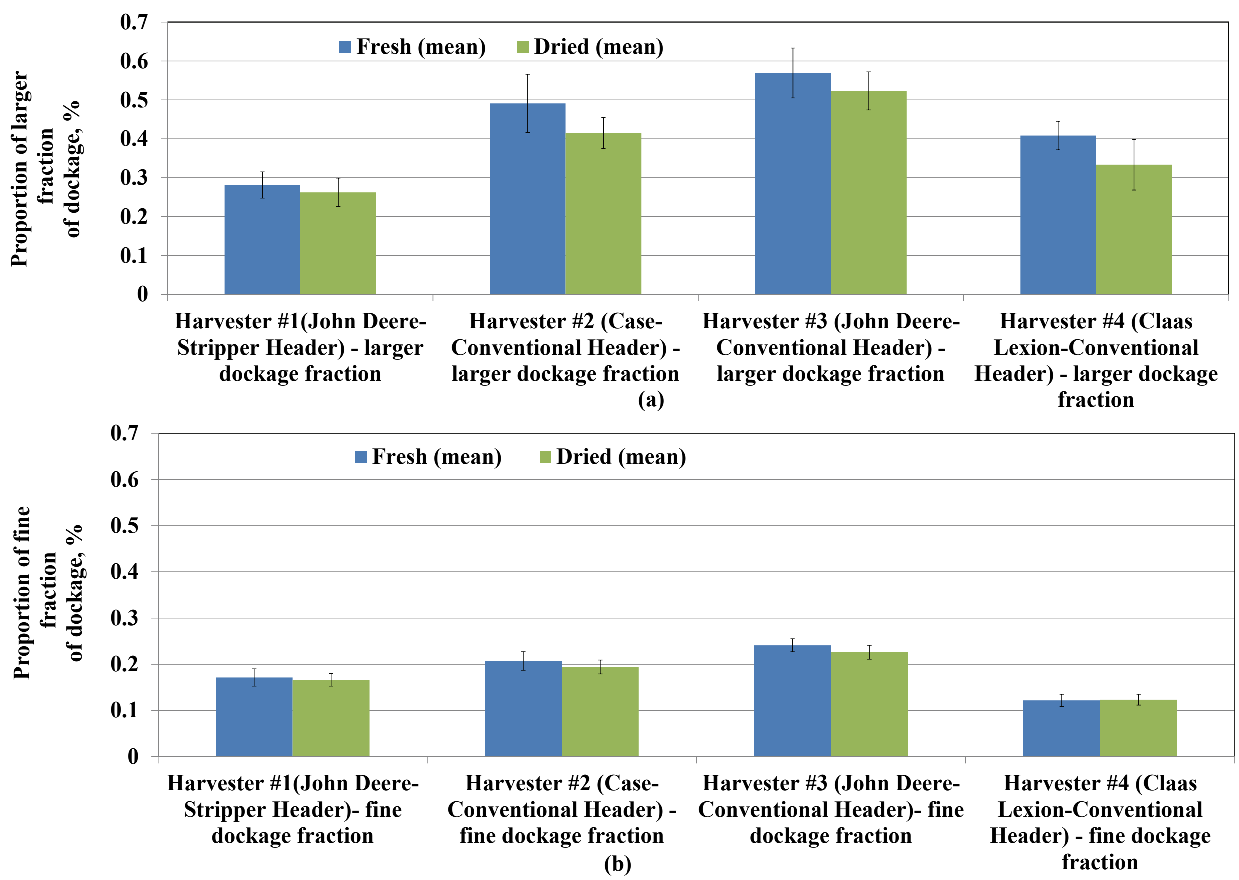


Figure 5. Proportion of (a) larger and (b) finer fractions of rice dockage resulting from using different harvesters and headers.

Table 7. Impact of wind and rainfall events on rice dockage.

Weather Condition	Mean Dockage (%)[a]	
	Freshly Harvested Samples	Dried Samples
Normal	0.53 ±0.05Aa	0.48 ±0.09Aa
Windy	0.89 ±0.37Bb	0.84 ±0.39Bb
Rainy	1.98 ±0.79Cc	1.63 ±0.67Dc

[a] Means with different capital and small letters in each row and and column of each category are significantly different at $p < 0.05$ level, respectively.

are compromised when rice stalk is fallen. Threshing, separation and cleaning of rice in the harvester are also compromised when the moisture content is high.

Statistical analysis (table 7) indicated that dockage during rainfall events was significantly higher ($p<0.05$) than during regular and windy weather events. There was also a significant difference ($p<0.05$) in dockage of dried and freshly harvested samples during rainy weather unlike during normal and windy weather conditions. Consequently, it can be concluded that rainfall and wind had a significant impact on rice dockage.

The obtained results clearly indicated that a significant proportion of freshly harvested rice samples obtained from growers with different harvesters during regular weather (for the whole harvest season) and those sampled during windy weather or collected at drying sites had dockage values below 1%. On the contrary, all of the samples obtained after rain events had dockage values above 1%. Even after drying, rice obtained after rainfall still had a considerable proportion (94%) with dockage values above 1% (table 8). The proportions of freshly harvested and dried samples with average dockage values below 1% as well as the average moisture contents of rice samples used for different categories of the experiments are shown in table 8.

Updating Shrink Chart

Based upon research conducted for the two consecutive rice harvest seasons, the average dockage for freshly harvested rice received at the drying site was 0.9%, which is significantly lower than the widely accepted and industrially used value of 2%. Dockage value was significantly low (0.5%) when the stripper header was used for harvesting of rice. However, bad weather conditions significantly increased rice dockage with nearly 2% under rain conditions. For industrial applications, it is recommended that under normal weather conditions rice dockage may be assumed at 1% for updating rice shrink chart.

Conclusions

The focus of this study was to identify the levels of rice dockage as affected by various factors and provide suitable recommendations for updating rice shrink chart. The dockage of freshly harvested rice with moisture contents (MCs) ranging from 18% to 27% wet basis (w.b.) varied between 0.2% and 2.0%. The average dockage was 0.79% in 2011 rice harvest season, slightly lower than 0.92% in 2010. Similarly, average value of dockage of dried rice with MC of 14±1% (w.b.) was 0.65% in 2011 and 0.78% in 2010 harvest seasons, again slightly lower than that of freshly harvested rice. There were no significant differences in dockage among studied rice varieties. The dockage results of different rice varieties (M104, M202, M205, and M206) used in 2011 were consistent with 2010 results, albeit slightly lower values were recorded in 2011. It was also observed that dockage was not significantly affected by harvest moisture content and geographical location of field. Dockage of rice samples increased trivially on dropping, approximately 0.03%. In particular, wind and rainfall events significantly increased dockage. The results also revealed that type of harvester and header affected dockage with stripper header indicating least dockage (0.5%) compared to conventional header (up to 0.8%). Average value of dockage for freshly harvested rice was determined to be 0.9% which was significantly lower than the widely accepted value of 2%. Therefore, dockage value of rice harvested under normal weather conditions may be assumed at 1% to update rice shrink chart. However, in the case of rain and windy conditions rice dockage as high as 2% may be expected. The best approach could involve avoiding harvesting during adverse weather condition and focusing harvest during regular weather condition when dockage could be minimized or be precisely estimated.

Table 8. Mean moisture and sample proportion in percentage with dockage values above 1%.

Weather Category	Mean Harvest Moisture (%, w.b.)	Sample Proportion with Dockage Above 1%	
		Freshly Harvested (%)	Dried (%)
Normal	0.22 ±0.03	13.73	3.92
Windy	0.18 ±0.02	45.83	12.50
Rainy	0.19 ±0.01	100	94.44

Acknowledgement

The investigators would like to express their appreciation for the great support received from the following personnel, Shweta Kumari, Rebecca Leong, Elizabeth Atungulu, Guang Shi, and Brian De La Cruz with sample collection and experiment implementation. We also express our thanks to Farmer's Rice Cooperative Sacramento, Butte County Rice Growers Association, Sean Daugherty of Daugherty farms, Camie Kaelin and Clarke Ornisaun for providing samples and harvesters used in this study, Cass Mutters of UC Davis for making contacts with growers, and the California Rice Research Board for research grants.

References

ASABE Standards. 2006. S352.2: Moisture measurement-ungrounded grain and seeds. St. Joseph, Mich.: ASABE.

Andrews, S. B., T. J. Siebenmorgen, E. D. Vories, D. H. Loewer, and A. Mauromoustakos. 1993a. Effects of combine operating parameters on harvest loss and quality in rice. *Trans. ASAE* 36(6): 1599-1607.

Andrews, S. 1993b. Effects of combine operating parameters on harvest loss and quality in rice. M.S. thesis. Fayetteville, Ark.: University of Arkansas.

Bennett, K. B., T. J. Siebenmorgan, E. Vories, and A. Mauromoustakos. 1993. Rice harvesting performance of Shelbourne Reynolds stripper headers. *Arkansas Farm Res.* 42(4): 4.

Mutters, R. G., and J. F. Thompson. 2009. *Rice Quality Handbook.* Publication 3514. Oakland, Calif.: University of California, Agriculture and Natural Resources.

Siebenmorgen, T. J., P. Counce, R. Lu, and M. Kocher. 1992. Correlation of head rice yield with individual kernel moisture content distribution at harvest. *Trans. ASAE* 35(6): 1879-1884.

USDA Federal Grain Inspection Service (FGIS). 1997. Chapt. 3: Inspection of rough rice. In *Rice Inspection Handbook*. Washington, D.C.: Federal Grain Inspection Service, United States Department of Agriculture.

Wilson, T. 2001. Combine harvester efficiency: Material other than grain or money on the ground. *Texas Rice* 1(8): 1-16.