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Cracking and breaking response in four rice varieties as influenced by fertilization regime and storage duration

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In Northern Ghana, harvesting of the bulk of paddy, which is cultivated under rain-fed conditions, coincides with the harmattan season. This season is characterized by low relative humidity and dry weather conditions which hasten drying and increase the tendency of the paddy to crack during milling. The farmers also store paddy for longer periods in anticipation of higher price in the open market, thus the paddy may deteriorate as a result of fluctuations in seasonal temperature and relative humidity. This study assessed the effects of fertilizer application regimes and storage duration on cracking and breaking during milling in 4 aromatic rice varieties. Across the varieties, grains that showed signs of cracks will eventually break during milling, and grain susceptibility to cracking significantly (P<0.05) increased when stored beyond 30 days. Gbewaa rice recorded significantly (P<0.05) higher cracking (49.2%) followed by Amankwatia (43.9%), CSIR-AGRA (40.4%) and Exbaika (40.3%). Fertilization regime of 2 basal applications and 2 topdressings at panicle initiation and booting-heading stages resulted in grains that were well-filled and thick to resist drying and cracking.

Key words: Aromatic varieties, nitrogen fertilizer, straight-milling, paddy cracking, consumer taste.

INTRODUCTION

In Ghana, straight-milled aromatic rice varieties are preferred by majority of rice consumers (Angelucci et al., 2013; Danso-Abbeam et al., 2014; Addison et al., 2015). However, straight milling is difficult to achieve due to a number of factors attributable to harvest maturity, and environmental conditions at harvest and during storage (Faraji et al., 2013). As a result, rice millers, especially in northern Ghana, are not able to conduct straight-milling at the required volume as there is a large percentage of cracked grains in the paddy supplied to the mills (Asuming-Brempong et al., 2011). The mills, therefore, resort to parboiling, a hydrothermal process that seals and cements the cracks, thus reducing breakages and improving head rice yield. Though the parboiling process is costly and time consuming, parboiled rice sells at a relatively lower price as compared to straight-milled rice

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on the Ghanaian market. This accounts for the large volumes of straight-milled rice imported into the country, which has negative consequences on the local rice industry.

In northern Ghana, harvesting of the bulk of paddy, which is cultivated under rain-fed conditions, coincides with the harmattan season. This season is characterized by low relative humidity and dry weather conditions. This condition hastens drying and increases the tendency of the paddy to crack during milling. In addition, smallholder farmers tend to store paddy for longer periods in anticipation of higher prices in the open market. Thus, the paddy may deteriorate during storage as a result of the seasonal fluctuation of temperature and relative humidity.

Rice cracking was known as sun-cracking by earlier researchers, latter research led to the observation that rice cracking was due to moisture absorption of dried rice (Schluterman and Siebenmorgen, 2007; Akowuah et al., 2012). Some studies in different varieties found that rice cracking begins at moisture content below 14.2 and 18.3% for crack resistant and crack susceptible varieties, respectively (Kumoro et al., 2019). Another factor that may cause paddy to crack before harvest is nonsynchronous blooming which leads to uneven grain maturity (Schluterman and Siebenmorgen, 2007; Akowuah et al., 2012; Kumoro et al., 2019). In bulk storage of paddy, moisture migration causes low-moisture grains to absorb moisture from the high-moisture grains and crack when the high-moisture grains had only 4 to 5% more moisture than the low-moisture grains (Akowuah et al., 2012). Thus, grains can crack before harvesting, during threshing, in bulk storage, and during transportation. The study assessed the relationship between rice cracking and breakage during milling and the effect of storage duration on cracking. Furthermore, the effect of three fertilizer application regimes on grain filling and cracking was evaluated.

MATERIALS AND METHODS

Field experiment

The study was conducted in partnership with three rice aggregators, namely Excel bit Com, Karaga Busaka ABC and Avnash Rice mill, all located in northern Ghana. The study was conducted at 9 paddy field sites (3 sites for each rice aggregator). Four (4) aromatic rice varieties: Gbewaa (Jasmine), CSIR-AGRA, Exbaika and Amankwatia were used. These varieties were planted from 22nd to 26th of July, 2016 at 9 study sites. Three fertilizer application regimes were used namely: FR1 = 1 basal + 1 topdressing at maximum tiller stage; FR2 = 2 basal + 1 topdressings at panicle initiation and FR3 = 2 basal + 2 topdressings at panicle initiation and booting-heading. For several decades now, treatment FR1 has been the farmer practice in the northern Ghana. However, due to continuous cropping leading to loss of soil fertility, this rate appears to be inadequate to achieve economic yield and optimum grain quality. Studies in India and the Philippines, suggest that two to three applications of nitrogen per crop cycle gives the highest nitrogen efficiency, and that more split applications are needed for long duration varieties and for lighter soils (Faraji et al., 2013; Rehman et al., 2013). The study modified the fertilizer application rate to enhance both yield and milling quality; although the effect on grain yield is captured in another study.

Harvesting and storage of samples

Freshly harvested paddy samples were sent to the CSIR-SARI Rice laboratory and threshed manually. Samples were transferred into Ziploc bags (©2014 S.C Johnson and Son Inc. Racine. W1 53403-22360 U.S.A) and stored in a cold room at the Institute (4°C, 30% RH) to minimize temperature fluctuation and adsorption of moisture. When the analysis began, samples were stored in sacks and on shelves to mimic the storage conditions of aggregators and farmers.

Determination of grain moisture content

Moisture content of the paddy was determined using a rice moisture meter Riceter f501 Series (KETT Electric Laboratory, 1-8-1 Minami-Magome Ota-Ku, Tokyo, 143-8507 Japan). Three sample readings were conducted and the average recorded. Cracking test on samples was conducted once every two weeks in the first month, followed by monthly test in other 5 months. Analysis of cracks in the harvested paddy was carried out at both Avnash Rice Mills and the CSIR-SARI Rice Laboratories. After thoroughly mixing, a sample of 2 kg was collected and spread thinly on a table. Nine sub-samples (weighing 30 g) were picked and mixed thoroughly. The sub-samples were then spread on a table and subdivided again into 4 equal parts using the coning and quartering method to obtain working samples. The working samples were then gently manually dehusked and the brown rice gently placed into a Petri dish. For any grain that breaks during the process, one piece is put into the Petri dish and the other(s) discarded. Units of 100 grains were dehusked and spread thinly on Petri dish and placed on a crack detector. Cracked and broken grains were separated, counted and percent cracked grains computed using the following equation. The procedure was repeated three times and the average percent cracked grains recorded.

$$\%\ Cracked\ grains = \frac{No\ of\ cracked\ grains}{100\ grains} \times 100$$

Determination of milling parameters

The paddy in sack was thoroughly mixed and winnowed, and a sample of 10 kg weighed and dehusked in a Satake Laboratory dehusker. The weights of husk and brown rice were recorded and the percent husk determined. Then 1 kg sample was dehusked and cleaned. Then 3 replicates of 200 g samples of the cleaned brown rice were milled in a Satake Laboratory Mill. After milling, the weight of the bran was recorded and the percent bran determined. The milled rice was cleaned, spread on a table and sub-samples were obtained. Broken grains were manually separated from whole lot and their respective percentages calculated. This process was replicated 3 times at each location.

Laboratory analysis

The following parameters were determined in the laboratory:

(1) Number of days at storage before milling
(2) % Paddy dryness over time
(3) % Cracking during milling at 0, 30 and 60 days after storage
(4) % Moisture content
(5) Milling recovery (Total milling yield, brown rice yield and head

Table 1. Milling parameters of four aromatic rice varieties cultivated in northern Ghana.

Variety	% Husk	% Bran	% Broken	% Head whole grain	% Crack
CSIR-AGRA	26.8	9.9	4.7	29.4	11.3
Amankwatia	31.6	10.0	6.2	58.5	12.9
Exbaika	27.5	11.1	4.6	21.6	14.7
Gbewaa	28.9	12.2	1.1	19.1	13.6
LSD	4.5	3.8	9.1	44.1	1.8
CV (%)	10.7	24.0	15.7	10.5	8.7
Se	3.0	2.6	6.2	30.02	1.2
P<5%	ns	ns	ns	ns	ns

Table 2. Pearson correlation coefficients between milling parameters of four aromatic rice varieties.

Correlation	AV % MC	AV % Cracks	% whole grain	% Broken	% Bran	% Husk
AV % MC	1	-0.150	-0.356	0.370	0.170	-0.191
AV % Crack	-0.150	1	-0.123	0.242	0.062	-0242
% whole grain	-0.356	-0.123	1	-0.878**	-0.114	0.092
% Broken	0.370	0.242	-0.878**	1	0.196	-0.482*
% Bran	0.170	0.062	-0.114	0.196	1	-0.703**
% Husk	-0.191	-0.242	0.092	-0.482*	-0.703**	1

"*" = Significant at 5%, "**" = Significant at 1%.

rice yield)

Statistical analysis

The data sets collected were subjected to analysis of variance, and treatment means separated using Least Significant Difference at 5% significance level. Correlation and regression relations between cracking and other parameters (% moisture content, duration of storage, days to milling, etc.) were computed.

RESULTS AND DISCUSSION

Response of varieties to milling

Most rice varieties are composed of roughly 20% rice hull or husk, 11% bran layers, and 69% starchy endosperm, also referred to as the total milled rice. In an ideal milling process this will results into the following fractions: 20% husk, 8 to 12% bran depending on the milling degree and 68 to 72% milled rice or white rice depending on the variety. In this study, Amankwatia, recorded the highest head rice yield of 58.5% while Gbewaa recorded the lowest of 19.1%. Percentage broken was relatively low, ranging from 1.1 to 6.2% (Table 1). This may be due to the fact that the paddy was dried to the desired moisture content and milled immediately. Low percent cracking was observed in CSIR-AGRA (11.3%) and Amankwatia (12.9%) as compared to Gbewaa (13.6%) and Exbaika (14.7%). In general, the recommended moisture content to mill rice is 14%, at this moisture content, rice has the maximum mechanical strength. Above this moisture, the grain is soft and would crush during milling. At moisture contents less than 14%, the grain becomes brittle and cracks or break during milling. Both instances lead to reduction in head rice yield (Schluterman and Siebenmorgen, 2007; Akowuah et al., 2012; Kumoro et al., 2019). Generally, a good quality paddy constitutes about 55% head rice, 15% broken, 20% husk, and 10% bran.

The results in Table 2 establish no significant relations between grain cracking and breaking during milling. Thus, all cracked grains will eventually break during milling. This may be due to the fact that some cracks may not go through the entire grain, while other cracks may be at the extreme tip of the grain. Although, there was no significant difference among the varieties in relation to percent crack and percent breakage, relatively higher percent breakages were observed in Exbaika (14.9%) and Gbewaa (16.5%) compared to CSIR-AGRA (13.2%) and Amankwatia (11.2%) (Figure 1). Figure 2 depicts the effect of variety on grain cracking across locations over a period of storage time. It can be observed that CSIR-AGRA (40.4%) and Exbaika (40.3%) showed relatively lower mean percentage cracking as compared to the other two varieties. Gbewaa rice recorded the highest percent cracking (49.2%).

Effect of length of storage on cracking

Figure 3 shows the effect of length of storage on percent cracking. Generally, percent cracking ranged from about

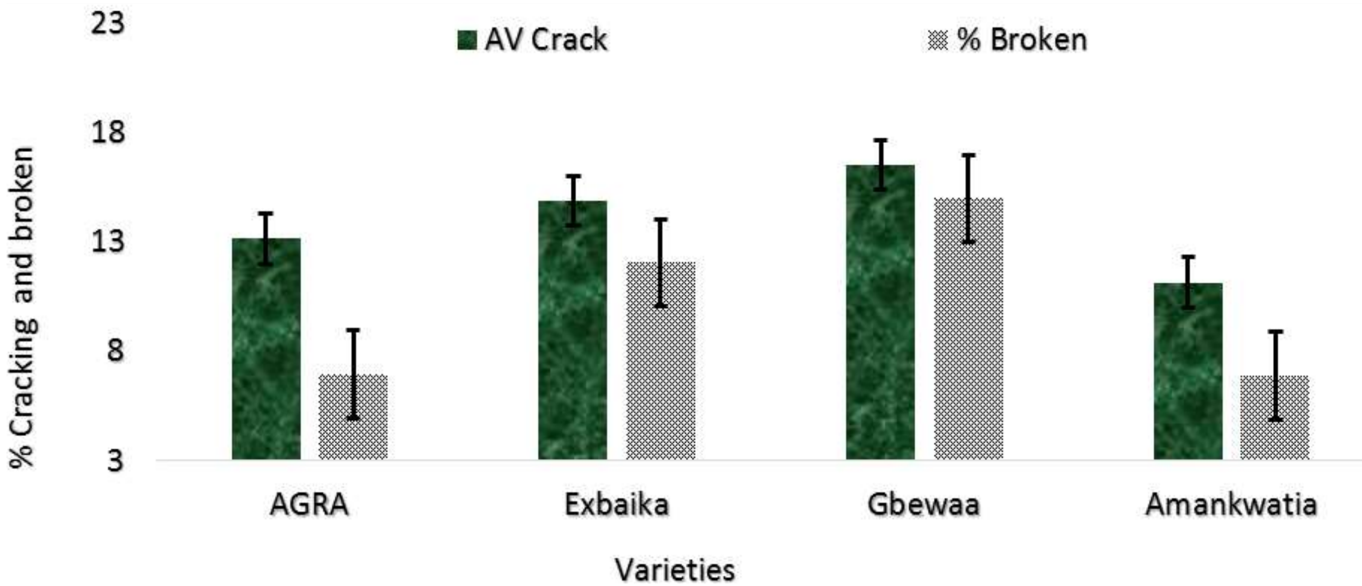

Figure 1. Relative susceptibility of four aromatic rice varieties to cracking and breakage during milling.

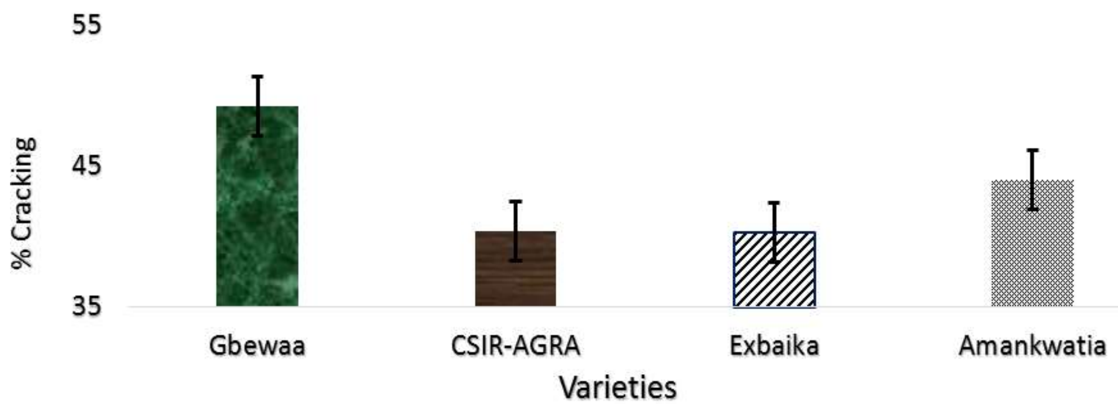

Figure 2. Relative susceptibility of four aromatic rice varieties to cracking.

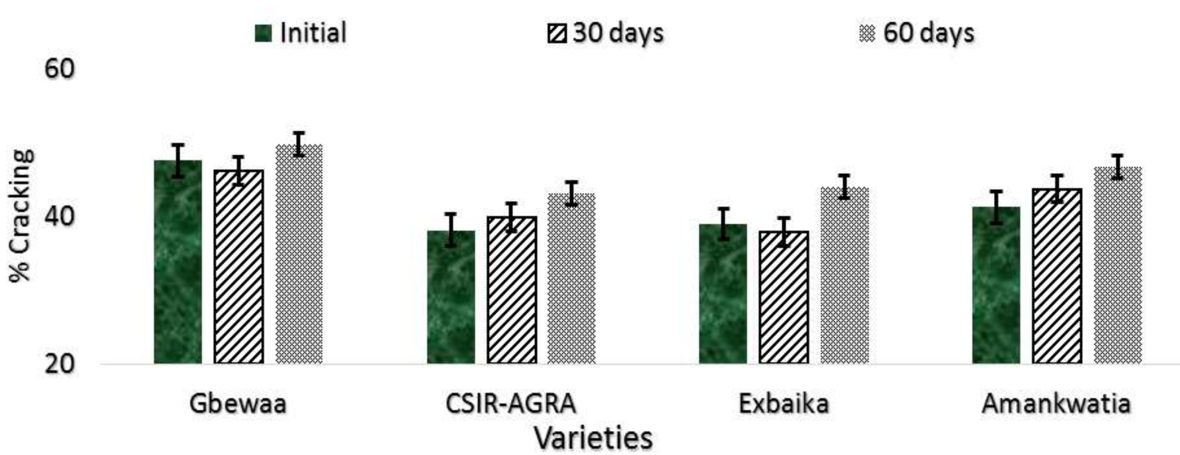

Figure 3. Effect of storage duration on percent cracks in four aromatic rice varieties in northern Ghana.

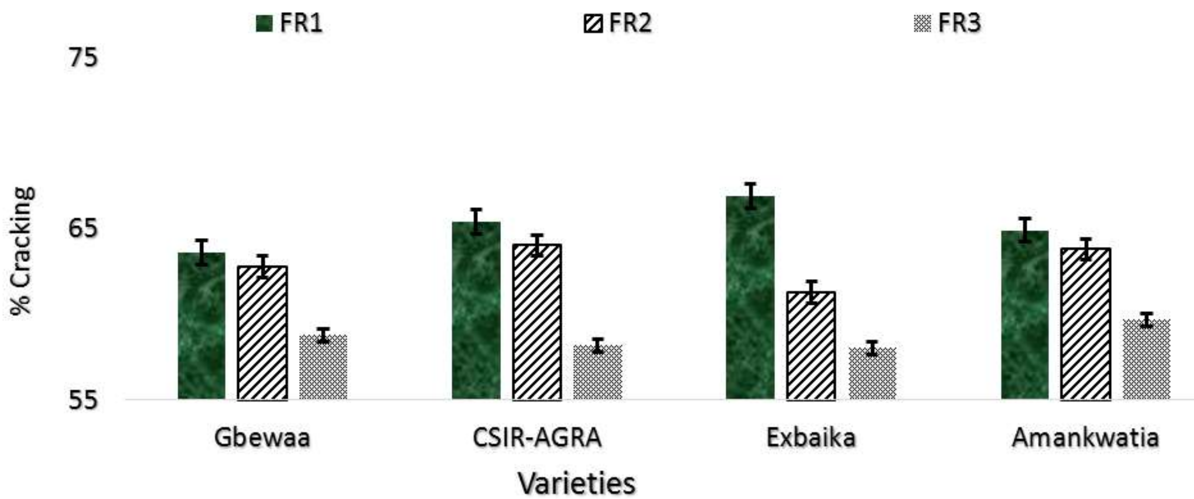

Figure 4. Effect of fertilizer management on percent cracking in four aromatic rice varieties after two months of storage. (FR1 = 1 basal + 1 topdressing at maximum tiller stage; FR2 = 2 basal + 1 topdressings at panicle initiation; and FR3 = 2 basal + 2 topdressings at panicle initiation and booting-heading).

38 to 54%. Depending on the storage duration and prevailing ambient conditions, the quality of grain will remain same or deteriorate in storage. There was no significant difference in cracking across the varieties at 0 and 30 days after storage. However, by 60 days after storage, Gbewaa rice showed significantly higher cracking percentage compared to three other varieties.

Effect of fertilizer management on cracking

Use of appropriate nitrogen application regimes has been postulated to enhance hardness and reduce breakages in rice (Rehman et al., 2013; Faraji et al., 2013; Tari and Amiri, 2015). Current practice of two split applications of the recommended rate has been found to result in inefficient use of N. In this case, most of the N applied is not available at the grain filling stage when presumably; the plants require lots of nutrients to accelerate grain filling (Tari and Amiri, 2015). Such grains are thin, dry-out readily and susceptible to cracking. Finding adequate nitrogen management regime in rice production could result in the production of grains that are well filled, thick to resist drying and resistant to cracking.

Figure 4 shows the effect of fertilizer treatment on grain cracking after three months of storage in northern Ghana. There was no significant difference between the first two splits, FR1 (1 basal + 1 topdressing at maximum tiller stage) and FR2 (2 basal + 1 topdressings at panicle initiation) except in Exbaika, where there was a significant differences. However, significantly lower percent cracking was observed in all four varieties at FR3 (2 basal + 2 topdressings at panicle initiation and booting-heading). This indicates that all four varieties responded significantly to increased split fertilizer rates. The higher the split fertilizer application, the more resistant the paddy is to cracking. These results correspond well with several earlier findings (Faraji et al., 2013; Rehman et al., 2013).

Conclusion

Cracks in paddy can occur before harvest, during threshing, drying, storage and even transportation depending on the ambient conditions. In this study, there was no direct relationship between paddy moisture content and percent cracking across the varieties. Overall, CSIR-AGRA Rice showed lower susceptibility to cracking compared to other 3 varieties. Fertilization regime of 2 basal applications and 2 topdressings at panicle initiation and booting-heading stages resulted in grains that were well-filled and thick to resist drying and cracking. Across the varieties, grains that showed signs of cracks will eventually break during milling, and grain susceptibility to cracking significantly increased when stored beyond 30 days. It is therefore recommended that farmers and aggregators do not keep their paddy for too long as that could affect milling quality. Where storage is inevitable, the environment should minimize possible exposure of the paddy to absorb moisture.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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