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Effect of Final Moisture Content, Cooling Time and Paddy Variety on Milling Quality of Rice (*Oryza sativa*, L.)

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ABSTRACT

The study was carried out to establish the effects of three factors -final moisture content (FMC), shade-cooling time (CT) and paddy variety on rice milling quality. Paddy was sun dried to final moisture contents ranging from 9.0 to 15.5% (on wet basis) and shade-cooled for 0, 6, 12, 18, and 24 h at ambient temperature (27.20 to 35.10°C). Five paddy varieties, TXD 88, TXD 306, SUPA, IRRITA 1, and IRRITA 2 were studied. The milling tests were carried out using a laboratory rice mill. Latin square design with 5 replications (5x5 orders) was used. Physical properties and milling quality in terms of total rice yield (TRY), head rice yield (HRY) and whiteness index (WI) were analyzed. The physical properties differed significantly (P<0.05) among varieties. SUPA had good size, shape and chalkiness whereas TXD 88 had poor quality for all these parameters. IRRITA 1 and IRRITA 2 produced higher TRY compared to other tested varieties. TXD 88 had higher whiteness index but lower HRY compared to other tested varieties. Higher yields, which were significantly different for TRY and HRY (P<0.05) were obtained at moisture content between 9.0 to 12.5% for TRY, but between 10.5 to 14.0% for HRY.

Key words: Drying, head rice yield (HRY), Rice varieties, Total rice yield (TRY) and Whiteness index (WI).

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INTRODUCTION

Within the worldwide-cultivated cereals, rice (*Oryza sativa* L.) stands out, constituting the basic food for large number of human beings sustaining two-third of the world population (Alizadeh and Rahmati, 2011). It is a staple food for many countries. Unlike other grains, such as wheat, corn, or oats, rice is cooked and consumed as a whole grain (Bryant and McClung, 2011). In Tanzania, rice is a major source of income, food and employment in rural areas, provides about 95% of the national food requirements and livelihood to more than 70% of the Tanzanian population (MAFC, 2009), accounted for 25.7% of the GDP and 22% of foreign exchange earnings in the year 2008.

The milling quality of rice may be defined as the ability of rice grain to stand milling and polishing without undue breakage so as to yield the greatest amount of total recovery and the highest proportion of head rice to broken (Graham, 2002). Milling quality affects three categories including trade quality (HRY and whiteness), cooking quality (amylose content, gelatinization temperature, gel consistency, aroma and flavor) and nutritional quality (thiamine and lysine contents) (Karbassi and Mehdizadeh, 2008; Mehdizadeh and Zomorodian, 2009). Ondier et al. (2010) and Yadav and Jindal (2008) also mentioned that milling quality is related to TRY, HRY and whiteness. TRY and HRY are defined as the percentages of total milled rice (broken + head) and head rice based on the paddy (rough rice) weight, respectively (Pan et al., 2007). Head rice, synonymous with "whole kernels" (USDA-FGIS, 2009) is expressed as milled grains that are 3/4 or more the original grain length.

The high values of TRY and HRY are essential for the effective rice breeding programs (Abozar et al., 2014). The cooking quality and hence the market price of broken rice is less than those of head rice (Iguaz et al., 2006). Whiteness, well-milled rice is expressed as the extent of bran removal from brown rice during the milling operation. This parameter is essential to estimate the nutritional value of rice including the amount of proteins, lipids, vitamins, and minerals (Abozar et al., 2014). Additionally, it is a valuable factor in terms of economic return of the milled rice (Gujral et al., 2002). Whiteness is often dictated by consumer requirements and decreases as milling progresses (Billiris et al., 2012). In some countries, whiteness is not a profound index of rice quality, while Tanzanians prefer to consume the rice with high whiteness. Researches have been devoted to reduce drying duration while maintains high TRY and HRY. Lanning and Siebenmorgen (2011) report significant interactions among drying, tempering (cooling), and storage conditions and their effects on milling quality and functionality, suggesting that changes in rice physicochemical properties are complex functions of post-harvest conditions. In addition, moisture content of rice at the time of milling play a significant role in the relationship between TRY, HRY and whiteness (Pearce et al., 2001; Cooper and Siebenmorgen, 2007; Bautista et al., 2009). Several studies on postharvest handling and rice milling quality have been done in the country (Lyinda and Tony, 2000; RLDC, 2009; MMA, 2010; USAID-COMPETE, 2010; BMGF, 2012).

While these studies are insufficient to improve the quality of the milled rice, little is known on effect of paddy milling conditions such as final moisture content, cooling time and paddy variety during milling processing. Since new and promising paddy varieties are still coming out and improving milling quality is an ongoing goal for the rice sector in the country, it is therefore necessary to test and evaluate conditions at milling that produce high-quality milled rice in the country.

This study therefore aimed to provide preliminary information regarding the extent of variability in rice milling quality with regards to moisture content, cooling time and rice varieties. This information save as benchmark for breeders, researchers, farmers, processors, administrators, policy makers and all stakeholders involved in rice industry. It also help the country to sustainably improve the quality of milled rice by developing effective and efficient supply chains in order to take full advantage of growing rice market opportunities.

MATERIALS AND METHODS

Five paddy varieties TXD 88, TXD 306, SUPA, IRRITA 1(Komboka) and IRRITA 2 (Tai) samples were purposively selected as research materials based on aroma, market and sales volume. According to ASA (2013) the seed market is dominated by TXD 306 for about 90% and the remaining 10% is distributed to 7% SUPA and 3% TXD 88. The two IRRITA varieties were among the newly introduced varieties which are strongly recommended by the government. SUPA is classified as strong aromatic paddy variety while TXD 88 and TXD 306 are semi-aromatic varieties.

Crop Husbandry

Seeds of the 5 paddy varieties were purchased from ARI-KATRIN (Agricultural Research Institute) and grown during dry season at Mkula village irrigation scheme in Morogoro, Tanzania. The seeds were sown on nurseries, and after 10 to 14 days they were transplanted into prepared field plots at spacing of 20 x 20 cm. The field was disc ploughed and harrowed followed by experimental plots layout (Completely Randomized Design -2 replications). Nitrogen fertilizer at 80 kg N/ha in the form of Urea (46% N) was equally split at two stages; *viz* initial tillering and at panicle initiation. Daily management of the experimental plots such as weeding, herbicides spray and bird scaring was done where necessary. No data was collected from the field.

Posthavest Handling

SUPA, IRRITA 1 and IRRITA 2 were harvested by cutting straws 15 to 25 cm above ground level, using sickles at 35 days after (50%) heading (DAH) and when 85% of the paddy grains look matured by eye measurement while TXD 88 and TXD 306 were harvested 10 days later, waiting until 85% of the grains mature as at 35 DAH, less than 85% was observed (AfricaRice, 2013). Threshing was done by beating panicles with wood/stick on tarpaulin sheet followed by winnowing. Improved open-sun drying regime was employed where each paddy sample (TXD 88, TXD 306; IRRITA 1, IRRITA 2 and SUPA) was thin-layer spread 2 cm on tarpaulin, hand raked after 20 min until it attained all the five desired moisture levels (9-9.5, 10.5 to 11, 12 to 12.5, 13.5 to 14 and 15 to 15.5%) (Kobra et al., 2010). Authors preffered open-sun drying regime as it is a common practice employed by majority smallholder farmers in the country. Postharvest handling, including drying were done during the dry season. In adittion, ambient temperature and relative humidity were recorded during drying. Moisture content was determined using the procedure below. All samples were shady-cooled at ambient temperature (27.20 to 35.10°C) before milling at five cooling time levels (0, 6, 12, 18 and 24 h).

Experimental Design

Latin square design (LSD) of orders (5x5) was employed, in which the rice Laboratory mill (ZACCARIA PAZ/1-DTA, Brazil) at Kilombero Plantation limited (KPL) was treated as experimental unity. Five paddy varieties, final moisture contents and cooling time were assigned as treatment, column and row, respectively.

Measurements

Moisture Content

To calculate moisture content, Superpro Moisture analyser (Grinder Crusher Type, Supertech Agroline, Denmark) was used. A 15 g of each paddy sample was poured into the grinder, then crushed and compressed in one operation as the lid tight to close the grinder before running the test. Moisture content was directly read from the display about 10 sec after pressing ON/TEST button. Three tests (triplicates) were done per sample and the average value was recorded. As the Superpro Moisture Analyser is heat sensitive, samples were left for 10 min to cool (after drying) before taking moisture measurement.

Total Rice Yield and Head Rice Yield

A 100 g paddy sample was milled by dehusking and polishing using ZACCARIA laboratory mill (PAZ/1-DTA, Brazil). The milled rice sample was immediately collected, sealed and allowed to cool to ambient temperature (27.20 to 35.10°C) before being weighed to obtain a direct TRY based on the following equation (Graham, 2002): TRY (%) = (W_t / W_p) x 100, where W_t (g) is the weight of total rice grains (head + broken) after milling, and W_p (g) is the weight of grains before milling. Whole grains plus three quarters or more of their original length were hand separated from the total milled rice and their weight recorded to obtain a direct HRY based on the following equation (Graham, 2002): HRY (%) = (W_d / W_p) x 100, where W_d (g) is the weight of head rice after milling.

Grain Dimensions And Chalkiness

Grain dimensions and chalkiness were estimated using the S21 Rice Statistic Analyzer, (LKL Technologia, Brazil). The equipment run with a Classficador S21 version 4.05 software. The fluorescent light on the S21 was turned on and approximately 50 g of whole grains weighed and emptied into sample receiver. Individual grains from the receiver passed beneath the attached camera when “long white” classification set up for the raw non-parboiled rice was opened in the capture mode on the software. The receiver image mode was stoped after all the grains had exited and their images captured. The chalkiness of the samples were then estimated by processing the captured images and applying the “basic filter chalky distribution” on the software. The percentage total chalky area for the sample was then recorded and reported as the percentage chalkiness of the sample. The grain dimensions were also estimated by applying the “advanced filter- lenth distribution” on the software. The average length (mm) and average width (mm) were recorded. The S21 was calibrated using a reference sample supplied by the manufacturer.

Whiteness

The degree of whiteness of milled rice samples was measured with a laboratory color meter (CR-400, Minolta Co., Ltd., Tokyo, Japan) utilizing the L, a, b uniform color space procedure. A 20 g of a whole kennel milled rice of each sample was placed in a small container of the color meter and the whiteness was individually measured and recorded. The value of L expresses the lightness value, a, and b are the red/green and yellow/blue coordinates of the L a b color space system.

Statistical Analysis

Grain dimensions and chalkiness data assessed according to the scale established by the Standard Evaluation System for Rice (IRRI, 2013a). Data was analyzed following analysis of variance using GenStat Discovery Edition 4 and means of final moisture contents, cooling time and variety treatments were compared based on Duncan Multiple Range Tests (DMRT) at 0.05 probability level. Trend analysis of TRY, HRY and Whiteness means was done using Microsoft Office Excel -2007.

RESULTS AND DISCUSSION

Grain Size

Grain size is one of the critical factors that influence milling quality of rice. The grain length of five rice varieties was recorded as shown on Table 1. Although all varieties were regarded as “long” there were significant differences ($P<0.05$) in grain length (size) among some varieties. TXD 88, TXD 306 and IRRITA 1; TXD 306 and IRRITA 2; SUPA and IRRITA 2 were not statistically different ($P>0.05$) from other varieties. The difference in length among varieties was probably due to the genetic variation. Unlike other cereals, uniformity, shape and size are considered the first characteristics of quality in rice, as it is consumed as a whole grain.

The milling quality of rice depends on many factors, including size and surface hardness of the grain. According to Roy (2003) and Mohapatra and Bal (2007) lower surface hardness facilitates breakage during milling, resulting to lower milled rice recovery and quality in the case of long grains compared to that of short grains. The flow ability of short grains through the milling chamber of friction type milling machine is higher than that of long grains, resulting into lower degree of breakage during milling which leads to production of high amount of head rice (FAO, 2004). According to MAFC (2009), in Tanzania, rice consumers prefer long to médium size aromatic grains. In addition, Campbell et al. (2009) reported that, long grain white rice with an intermediate level of starch dominates the markets in most of West Africa except for those markets that prefer parboiled or broken rice. The physical dimensions of rice kernels are of vital interest to those engaged in the rice industry (Pan et al., 2007). New developed rice varieties need to attain these characteristics, for they influence in cleaning, grading

Table 1. Physical Parameter means related to milling quality for five Rice varieties.

Rice Variety	Physical Properties of milled Rice					
	GL (mm) ± SE	Size*	GLW Ratio ± SE	Shape*	% Chalky ± SE	Description*
TXD 88	6.74±0.01[a]	Long	2.85±0.01[a]	Medium	49.65±1.81[d]	Large
TXD306	6.94±0.05[ac]	Long	3.20±0.03[bc]	Slender	26.32±1.79[b]	Large
SUPA	7.14± 0.15[d]	Long	3.14±0.07[bc]	Slender	22.68±1.18[a]	Large
IRRITA 1	6.75±0.01[ab]	Long	3.12± 0.01[b]	Slender	28.68±1.61[b]	Large
IRRITA 2	7.03±0.10[cd]	Long	3.23± 0.04[c]	Slender	40.01±2.57[c]	Large
Mean	6.92± 0.04		3.11± 0.03		33.47± 2.17	
CV	3.418		5.125		32.37	
P value	0.001		<.001		<.001	
LSD	0.1899		0.087		3.046	

*According to the Standard Evaluation System for Rice (IRRI, 2013a). Means not sharing a common superscript letter in a column are significant different (P< 0.05) by DMRT. L.S.D = Least Significant Differences of means at (P< 0.05), S.E = Standard Error, C.V = Coefficient of Variation, GL = Grain length, GLW ratio = Grain length-width ratio.

equipment, drying operations, processing and marketing (Wenela, 2013).

Grain Shape

The grain shape (Length: width ratio) of the five rice varieties is as shown on Table 1. Four out of five varieties tested were slender while the remaining variety (TXD 88) was of medium shape and was statistically different from all rice varieties. The study by Wenela (2013) reported similar results for the tested variety except TXD 88, which was categorized as slender. The shape indicated highly significant differences (P<0.05) among varieties. The difference in shape among the five rice varieties was probably due to genetic variations. Appearance is a critical quality attribute for rice as rice buyers, millers and consumers judge the quality of rice on the uniformity of kernel size and shape as well as the appearance (Siebenmorgen et al., 2014). Studies have also indicated that grain shape contributes to milling loss. Siebenmorgen and Qin (2005) and Roy et al. (2008) found the size of the grain to have great effect on milling recovery; bold and short grains break less during milling than long and slender ones. Mass loss and breakage are affected by cultivar, kernel shape, and thickness of aleurone layer (Liang, 2008). Grain size and shape are the most critical criteria of rice quality that breeders have to consider in developing new varieties (Wenela, 2013). If a variety does not conform to recognized standards for grain size, shape and weight it can be rejected.

Chalkiness (Opacity)

All five varieties described large chalkiness by the Standard Evaluation System (Table 1). Chalkiness showed highly significant difference (P<0.05) among tested varieties. Although TXD 306 and IRRITA 1 were not statistically different from each other, they were found to be statistically different from all other rice varieties at P<0.05. Similar results reported by Kibanda (2001, 2008) whose findings showed highest and lowest chalkiness in TXD varieties (220 and 275) and SUPA, respectively. The difference in chalkiness of the five rice varieties was probably due to genetic variations and external factors like moisture content at harvest, night-time air temperature and non uniform maturity. Cooper et al. (2008) found dramatically chalky increase in several cultivars as night-time air temperatures increase. According to Cnossen et al. (2002) and Graham (2002) chalkiness occurs when rice is harvested at too high moisture level or in varieties of non uniform maturity in which excessive numbers of immature kernels exist. Chalkiness in rice kernels is an undesirable characteristic as it degrades the visual appearance, milling, cooking and processing quality of milled rice. Chalky kernels tend to break more during milling as the characteristic nature of chalkiness offers weaker points than the translucent non-glutenous grains (Kibanda, 2001, 2008; Siebenmorgen et al., 2014). Excessive chalkiness is undesirable for many processed products because of non uniformity produced by over processing chalky kernels under usual processing conditions (Graham, 2002).

Total Rice Yield (TRY)

The rice varieties affect total rice yield of the milled rice. Milling quality in terms of TRY showed some significant differences (P<0.05) among rice varieties (Table 2). TXD 88 had the lowest TRY that was statistically different from all other varieties. TXD 306 and SUPA were not statistically different in TRY at P > 0.05 which was also observed for IRRITA 1 and IRRITA 2. The variability of TRY may be related to the different behaviors of rice varieties during separation of husk from kernel, like: kernel shape, porosity of starch granules and presence of chalkiness. For example, Razavi and Farahmandfar (2008) and Abozar et al. (2014) reported existing significant differences (P<0.05) of 1000-grain weight, unit mass, bulk density and porosity among tested rice varieties in the case of rough rice. According to Liang (2008) and Alizandeh and Rahmati (2011) yield of total

Table 2. Comparison of milling quality of five rice varieties, final moisture content and cooling time by DMRT.

Rice Variety	Mean Values		
	TRY% ± SE	HRY% ± SE	WI ± SE
TXD 88	69.05 ± 0.635[a]	51.29 ± 1.643[a]	70.26 ± 0.650[c]
TXD 306	71.32 ± 0.411[b]	60.79 ± 1.830[b]	66.36 ± 1.083[b]
SUPA	71.57 ± 0.310[b]	61.37 ± 4.076[b]	63.51 ± 0.981[a]
IRRITA 1	72.72 ± 0.142[c]	65.51 ± 2.201[b]	66.10 ± 0.893[ab]
IRRITA 2	73.13 ± 0.314[c]	62.64 ± 3.065[b]	66.91 ± 0.573[b]
Mean	71.56 ± 0.333	60.32 ± 1.480	66.63 ± 0.563
P value	<.001	<.001	0.003
Final moisture content %			
15-15.5	70.61 ± 0.980[a]	52.63 ± 2.405[a]	66.03 ± 1.095[a]
13.5-14	71.02 ± 0.892[a]	62.21 ± 3.319[c]	67.34 ± 1.218[a]
12-12.5	71.92 ± 0.603[b]	65.70 ± 2.235[c]	66.79 ± 1.359[a]
10.5-11	71.23 ± 0.562[b]	63.83 ± 3.036[c]	66.10 ± 1.311[a]
9-9.5	72.41 ± 0.595[b]	57.22 ± 2.501[b]	66.88 ± 1.721[a]
Mean	71.56 ± 0.333	60.32 ± 1.480	66.63 ± 0.563
P value	<.001	<.001	0.807
Cooling Time (h)			
0	71.17 ± 1.110[a]	61.58 ± 3.530[a]	66.38 ± 1.230[a]
6	71.33 ± 0.919[a]	59.42 ± 3.730[a]	66.88 ± 1.360[a]
12	71.94 ± 0.480[a]	60.51 ± 1.410[a]	67.10 ± 0.950[a]
18	71.89 ± 0.740[a]	58.64 ± 4.337[a]	65.02 ± 1.590[a]
24	71.44 ± 0.590[a]	61.64 ± 4.080[a]	67.75 ± 1.300[a]
Mean	71.56 ± 0.333	60.32 ± 1.480	66.63 ± 0.563
P vale	0.083	0.507	0.309
CV	2.325	12.26	4.227
LSD	0.6505	4.561	2.716

L.S.D = Least Significant Differences of means at (P< 0.05), S.E = Standard Error, % C.V = % Coefficient of Variation, TRY % = Total Rice Yield percentage, HRY% = Head Rice Yield percentage, WI= Whiteness index, FMC % = Final Moisture Content percentage. Means not sharing a common superscript letter in a column.

milled rice is influenced by proportion of hull and amount of fine endosperm particles, cultivar and thickness of aleurone layer. The mechanical properties of their kernel and bran may also be different, which needs more research. The TRY means indicated some significant differences (P<0.05) among final moisture contents which increased as final moisture content decreased from 15.5 to 9.0% (Table 2, Figures 1 and 3a and 3b). However, no significant differences in TRY were found in samples with moisture content greater than 13.5%; likewise no significant differences were found in samples with moisture content below 12.5% but the latter resulted in higher values of TRY. These two groups differed significantly in TRY.

The highest TRY value obtained here (72.46%) exceed the maximum achievable TRY of current commercial miller which is 65% (IRRI, 2013b). However, Imoudu and Olufayo (2000) recommended 12% moisture content for achieving the highest TRY. From the results, it is observed that TRY is influenced by moisture content of paddy at milling. These results are supported by other researchers (Imoudu and Olufayo, 2000; Miah et al., 2002) who found increase in TRY with decreased moisture content for tested varieties. TRY increased with decreasing moisture content from 12 to 8%, for both parboiled and unparboiled samples of Tarom and Fajr varieties (Abozar et al., 2014). With the exception of IRRITA1, final moisture content showed a linear relationship for all other varieties (TXD 88, TXD 306, SUPA and IRRITA 2) as shown on Figure 3a and 3b. IRRITA 1 showed a positive second degree trend similar but opposite to HRY trends. It is a new released variety, thus more research need to be done to explain the observed trend. The effect of cooling time on the values of TRY for the tested varieties is presented in Table 2. TRY did not show significant differences (P>0.05) in milling quality between the shade-cooling times at the ambient temperatures studied. It showed a third order quadratic trend (Figure 2). This may be attributed to the fact that the cooling time from 0 to 24 h was not sufficient to develop grain fissures and the sun-drying temperature was closer to immediate cooling temperature. When drying rough rice, the glass transition temperature (Tg), the temperature at which a state transition occurs causing the rice to change from a ‘glassy’ to a ‘rubbery’ state or vice versa, plays a significant role in the occurrence of fissure formation (Cnossen and Siebenmorgen, 2000; Cnossen et al.,

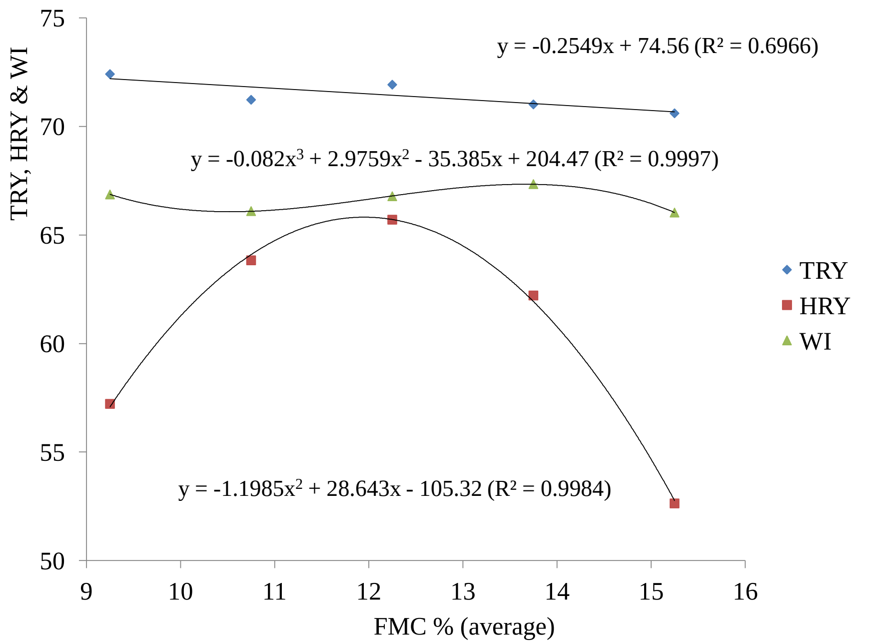

Figure 1. An estimated relationship between final moisture content and milling quality (TRY, HRY and Whiteness).

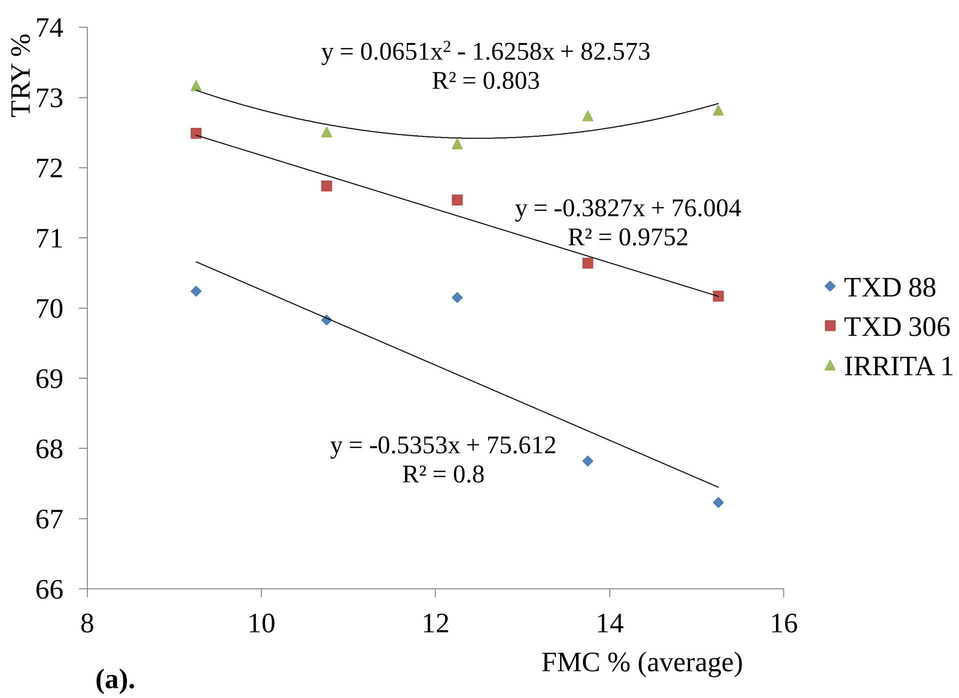

Figure 3a. An estimated TRY response of tested rice varieties showing a linear and nonlinear relationship.

2002). State transitions can occur by extended drying using high-temperature air or when kernels are cooled below Tg immediately after drying (Cnossen and Siebenmorgen, 2000). Therefore, for this study, it is possible that a state transition into the rubbery region did not occur during cooling as the sun-drying temperature

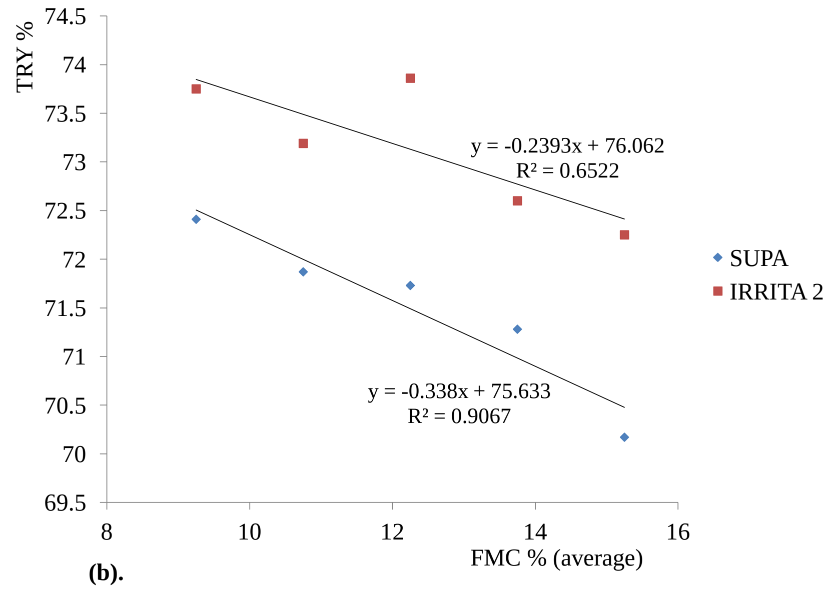

Figure 3b. An estimated TRY response of tested rice varieties showing a linear relationship.

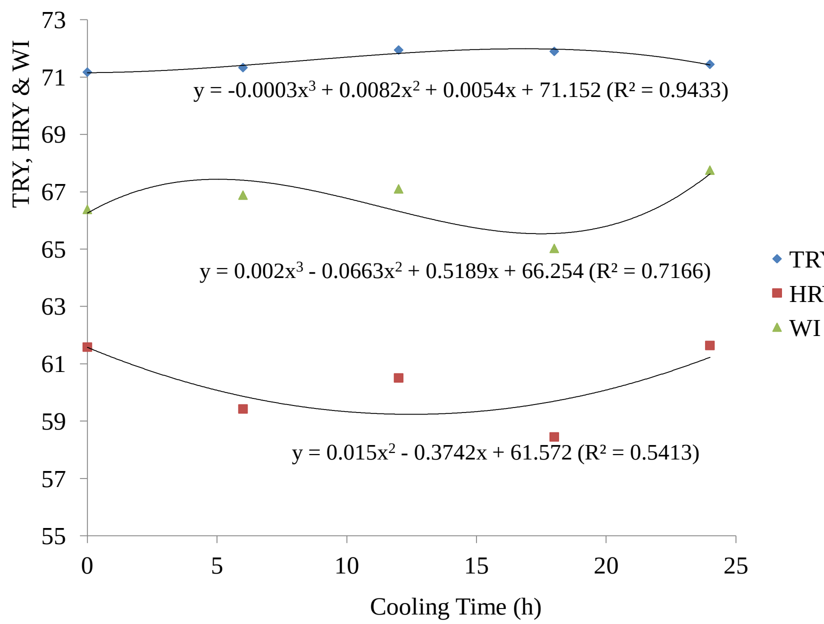

Figure 2. An estimated nonlinear relationship between cooling time and milling quality (TRY, HRY and Whiteness).

was closer to immediate cooling temperature and the cooling time from 0 to 24 h was not sufficient to develop grain fissures.

Head Rice Yield (HRY)

The effect of variety on HRY is shown on Table 2 and Figure 4a and 4b TXD 88 had the lowest HRY and was statistically different ($P<0.05$) from all the other rice varieties which were not statistically different ($P >0.05$) from each other. The lowest HRY record of TXD 88 was probably due to high chalkiness index, lowest size and larger shape compared to other tested varieties (Table 1). Previous studies by Hashemi et al. (2008) revealed that

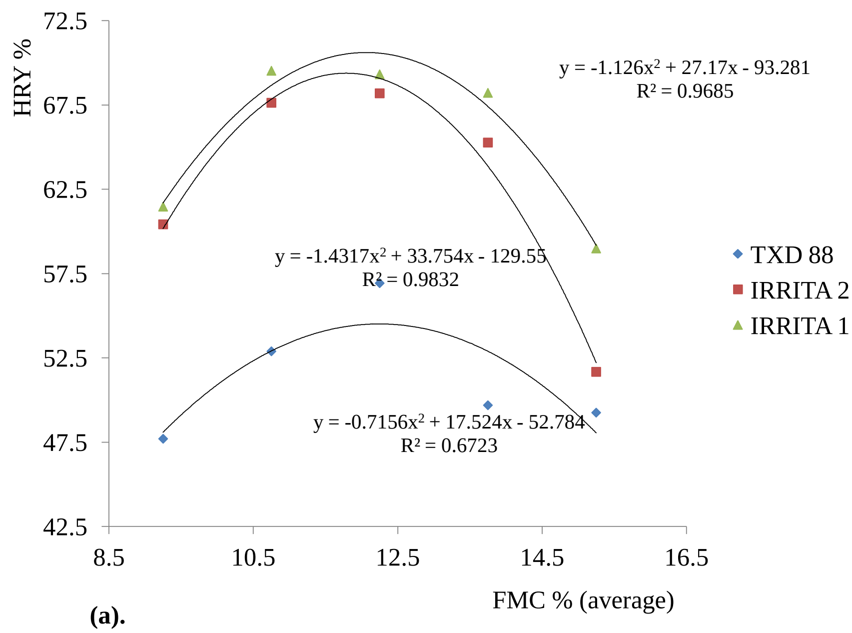

Figure 4a. An estimated HRY responses of tested rice varieties showing a nonlinear relationship.

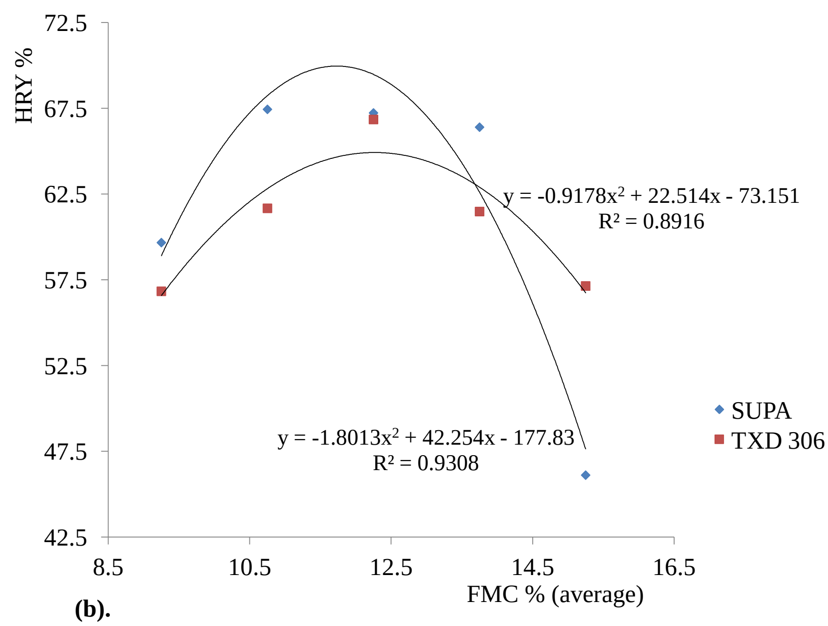

Figure 4b. An estimated HRY responses of tested rice varieties showing a nonlinear relationship.

each rice variety has its own susceptibility to fissuring; moisture stresses produce fissured grains more in bold varieties than in long-grain or long, slender-grain varieties. According to Graham (2002) chalkiness detracts from general appearance and usually results in lower milling yields since chalky kernels tend to break more during milling resulting in low HRY. Siebenmorgen et al. (2007) found that the harvest moisture content at which HRY is máximum, differ significantly among long-grain and médium-grain cultivars. HRY showed some significant differences ($P<0.05$) in final moisture content of tested varieties (Table 2 and Figures 1 and 4a and b), No significant differences in HRY were observed for samples with final moisture content between 10.5 to 14.0%. These samples were significantly different from higher (15.0 to 15.5%) and lower (9.0 to 9.5%) final moisture content. This is because a state transition into the rubbery region happens during extended drying from 10.5 to 9.0% final moisture content, thus resulting into HRY reduction. Previous studies (Cnossen and Siebenmorgen, 2000; Cnossen et al., 2002; Seibenmorgen et al., 2005; Hashemi et al., 2008) indicated that while drying rough rice using air temperatures above the rice glass transition temperature (Tg), kernels will fissure if a sufficient portion of the kernel surface change to a glassy state while the interior remains in the rubbery state, a condition that can result from extended drying. Higher HRY recovery were obtained at 10.5 to 14.0% FMC which is less compared to 19.0 to 21.0% for long-grain cultivars and 22.0 to 24.0% for medium-grains (Siebenmorgen et al., 2007).

This difference is attributed by variation of ambient temperature during kernel development. Cooper et al. (2008) confirmed that increasing levels of night time air temperatures during grain filling stages are strongly correlated to increasing levels of chalkiness and reduced HRYs. Figure 1, 4a and b shows a second order quadratic trend with respect to HRY and FMC. Similar trends have been reported by other researchers (Fan et al., 2000; Siebenmorgen et al., 2007). It may be attributed to the fact that too dried grains possessed sun cracks and therefore broke during milling (Fan et al., 2000). In addition, too wet grains would not be able to withstand milling pressure and broke badly during milling (Siebenmorgen et al., 2014). Both conditions either too dry or too wet result in low HRY.

The effect of cooling time on head rice yield (HRY) for the tested varieties is presented in Table 2. HRY did not significantly differ (P>0.05) by shade-cooling time at ambient temperature (27.2 to 35.1ºC). It shows a second order quadratic trend (Figure 2). It may be attributed to sun-drying temperature might have been closer to immediate cooling temperature, insufficient enough to develop grain fissures. Studies by Seibenmorgen et al. (2005) reported that the occurrence of fissuring was less for low drying temperature closer to immediate storage temperature; and all fissures occur within 24 h after drying, regardless of the drying temperature and variety, are completely formed by 48 h. According to Hashemi et al. (2008) time after drying (probably shade cooling at ambient temperature) is required before fissures developed, most kernels fissured within 48 h after drying but additional fissures developed at a slower rate for another 72 h thereafter.

Whiteness

Rice whiteness differed significantly (P<0.05) among some rice varieties. TXD 88 had the highest whiteness index, which was statistically different (P<0.05) from all rice varieties as shown on Table 2. This may be due to the fact that the TXD 88 had unique physical and chemical properties, such as chalkiness and shape (Table 1) that affected its whiteness. Rice whiteness (as a measure of milling degree) depends on such parameters as grain chalkiness, size and shape. Long and thin grains require more passes in order to achieve a gentle milling while medium/short and thick grains can be treated by a lesser amount of passes (Yada and Jindal, 2001). A study by Siebenmorgen et al. (2006) indicated that at a given milling duration, whiteness index varied among cultivars. The study specifically showed that whiteness index levels of two long-grain hybrids were lower than four long-grain cultivars across several milling durations, suggesting that different cultivars have unique physical or chemical properties that affect their milling characteristics. Final moisture content had no significant effect (P>0.05) on whiteness index (Table 2), showing a third order quadratic trend (Figure 1). However, the degree of milling or whiteness is influenced by the grain hardness, size and shape, depth of surface ridges, bran thickness and milling efficiency (FAO, 2004). It was reported that harder rice requires greater energy to obtain the same degree of milling or whiteness (Roy, 2003; FAO, 2004). Yan et al. (2005) found a direct correlation between increased moisture content and whiteness of embryo rice (rice with embryo). Abozar et al. (2014) also reported a significant effect (P<0.01) of moisture content on whiteness, whereas the whiteness increased from 33.8 to 35.6% with the increase of moisture content from 8 to 12%. They concluded that 12% moisture content is the best level to produce high quality milled rice. The difference of the finding from other researchers could be due to the different methods used.

In this study we used IRRITA 1 and 2, TXD 88 and 360, and SUPA whereas other rsearchers used Taron and Fajr varieties (Abozar et al., 2014). As a results final moisture content levels from 9.0 to 15.5% did not impart any significant hardness on rice grains. The effect of cooling time on the degree of milling or whiteness mean values for the tested varieties is presented in Table 2. Shade cooling time at ambient temperature (27.2 to 35.1ºC) had no significant effect on whiteness (P>0.05). It shows a third order quadratic trend (Figure 2). One foreseen consideration in milling quality is the effect of storage duration (cooling time) on whiteness. Some studies revealed that, as storage duration increased, milling duration had to be increased to achieve a consistent whiteness (Pearce et al., 2001; Cooper and Siebenmorgen, 2007). Since the milling duration was kept constant in this study, the cooling time from 0-24h was not sufficient to significantly affect whiteness. These findings of the effect of cooling time (0 to 24 h) at ambient temperature (27.2 to 35.1ºC) and relative humidity (36.40 to 72.10%) on quality of the milled rice tested (TRY, HRY and whiteness) hold true when the paddy is stored at cool and dry place preferably hermetic storage because dried rough rice (paddy) is hygroscopic and reacts to every environment to which it is exposed.

CONCLUSION AND RECOMMENDATION

The five tested varieties showed great variability in physical properties in terms of size, shape and chalkiness composition. That variability was somewhat a common feature in tested varieties and directly influenced the quality of milled rice. SUPA variety had good size, shape and chalkiness whereas TXD 88 had poor quality for all these parameters. IRRITA 1 and IRRITA 2 produced higher TRY compared to other tested varieties. TXD 88 had higher whiteness index and lower HRY compared to other tested varieties. This means that the higher the chalkiness content, the more the whiteness and vice versa. TRY showed not only variability, but an increasing trend as final moisture content decreased from 15.5 to 9.0% in all varieties except IRRITA 1. HRY showed a second order quadratic trend in all varieties a typical characteristic effect of moisture content on HRY. Higher TRY and HRY recovery were obtained at 9.0 to 12.5% and 10.5 to 14.0% FMC, respectively. As the chief element in fixing the value of paddy is the amount of “head rice” (whole grains), which can be milled out of it, therefore paddy should be dried gradually to the moisture content of about 10.5 to 14% for effective milling. Whiteness was not significantly affected by final moisture content. Findings also indicate that the cooling time from 0 to 24 h at ambient temperature (27.2 to 35.1°C) and relative humidity (36.40 to 72.10%) had no significant effect on quality of the milled rice tested (TRY, HRY and whiteness).

This study should serve as the foundation for future research regarding the extent of variability in rice milling quality with regards to moisture content, cooling time and varieties, in other rice producing areas in Tanzania. The study findings suggest that several measures should be considered in combination when evaluating the quality of milled rice. Relying on either TRY, HRY or whiteness single indicator is inadequate because each indicator might present some drawbacks. For example TXD 88 showed highest whiteness but lowest TRY and HRY values. The study should be replicated in different design setting as well as for different rice varieties in order to obtain further findings. Further research on the interaction effect of paddy varieties and final moisture content factors on milling quality of rice should be conducted. In addition, research can be conducted to identify constraints, which if resolved, can improve quality of the milled rice. This should include factors such as moisture content at harvest, drying regime and milling type in a form that improves the quality of milled rice, while safeguarding the nutrition.

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