EFFECT OF FINAL MOISTURE CONTENT, COOLING TIME AND PADDY VARIETY ON MILLING QUALITY OF RICE IN KILOMBERO DISTRICT, MOROGORO, TANZANIA

KULWA FURAHISHA

A DISSERTATION SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN FOOD SCIENCE OF SOKOINE UNIVERSITY OF AGRICULTURE. MOROGORO, TANZANIA.

2014

ABSTRACT

Drying and milling of paddy are the key processes and critical post-harvest operations influencing the quality of the milled rice. The current study was carried out to establish the effects of three factors -final moisture content, shade-cooling time and paddy variety on rice milling quality. Paddy was sun dried to final moisture contents ranging from 9-15.5% (on wet basis) and shade-cooled for 0, 6, 12, 18, and 24 hours at ambient temperature (27.20 – 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 analysed. 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. Final moisture content influenced quality of the milled rice. Higher yields, which were significantly different for TRY and HRY ($P<0.05$) were obtained at moisture content between 9-12.5% for TRY, but between 10.5-14% for HRY. Final moisture content had no significant effect on whiteness index. Shade-cooling time had no significant effects on TRY, HRY and whiteness. 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 – 14% for effective milling.

DECLARATION

I, **Kulwa Furahisha** do hereby declare to the Senate of Sokoine University of Agriculture that this dissertation is my own original work done within the period of registration and that it has neither been submitted nor being concurrently submitted in any other institution for a degree award.

Mr. Kulwa Furahisha

(MSc. Candidate)

18/11/2014

Date

The above declaration confirmed

Dr. Lucy Mlipano Chove

(Supervisor 1)

19/11/2014

Date

Mr. Davis Chaula

(Supervisor 2)

19/11/2014

Date

COPYRIGHT

ACKNOWLEDGEMENT

I am initially expressing my thanks to the Almighty Allah for taking me this far in my academic sojourn notwithstanding myriads of challenges.

I extend my sincere gratitude and respect to my supervisors Dr. Lucy Chove and Mr. Davis Chaula of SUA, Department of Food Science and Technology for their tireless effort and constructive comments, critical advices and valuable suggestions and support throughout my study. Their knowledge and experience through the long discussions that we had, have greatly contributed to the quality of this work. I am also thankful to all instructors and members of staff from the Department of Food Science and Technology at SUA and my fellow post graduate students.

I am also grateful to Kilombero Plantation Limited (KPL) and Africa Rice Center (ARC) for providing the laboratory facilities. My appreciation specifically goes to KPL Crop Production Manager Mr. Murray Dempsey and ARC Regional Representative for East and Southern Africa Dr. Paul Kiepe for linking me with these organizations. Thanks to Dr. John T. Manful and Mr. Seth Graham-Acquaah for sample analysis at ARC Headquarter, Cottonou, Benin.

Special and most distinguished word of appreciation goes to my Sponsor, the Eastern Africa Agricultural Productivity Programme (EAAPP) for the financial support towards this study. I wish to express my profound gratitude to the Ministry of Agriculture, Food Security and Cooperatives (MAFC) for granting me leave to pursue postgraduate studies culminating to the award of MSc. degree.

DEDICATION

This work is dedicated to my beloved daughter Mlinda, K. Furahisha, may the Almighty Allah bless her, Amen.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

LIST OF ABBREVIATIONS AND SYMBOLS

ANOVA	Analysis of Variance
ARC	Africa Rice Centre
ARI	Agricultural Research Institute
ASA	Agricultural Seed Agency
BMGF	Bill and Melinda Gates Foundation
COMPETE	Competitiveness and Trade Expansion program
DMRT	Duncan's Multiple Range Test
FAO	Food and Agriculture Organization of the United Nations
FGIS	Federal Grain Inspection Services
FMC	Final Moisture Content
FtF	Feed the Future program
GDP	Gross Domestic Product
HRY	Head Rice Yield percentage
IRRI	International Rice Research Institute
KATRIN	Kilombero Agricultural Training and Research Institute
KPL	Kilombero Plantation Limited
MAFC	Ministry of Agriculture Food Security and Cooperatives
MMA	Match Maker Associates
NRDS	National Rice Development Strategy
RLDC	Rural Livelihood Development Company
SUA	Sokoine University of Agriculture
TRY	Total Rice Yield percentage
USA	United States of America
USAID	United States Agency for International Development

USDA	United States Department of Agriculture
WI	Whiteness Index
%	Percent
'	Minute
"	Second
cm	Centimetre
g	Gram
h	Hour
ha	Hectare
kg	Kilogram
min	minute
mm	millimetre
N	Nitrogen
°	degree
°C	degree Celsius
R^2	Coefficient of Determination
t	Tonne
TZS	Tanzania Shilling

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background Information

Within the worldwide-cultivated cereals, rice (*Oryza sativa* L.) stands out, constituting the basic food for large number of human beings and sustaining two-third of the world population (Alizadeh *et al.*, 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). The crop ranks second only after wheat in terms of area of cultivation and production m (Kibanda, 2001).

While the production and consumption of rice is concentrated in Asia, which accounts for about 92% of the world's total production (Kibanda, 2008), it is also an important crop in specific regions of North and South America, Europe and Africa.

In Tanzania, rice is an important staple food particularly among the rapidly expanding urban population and ranks second after maize in terms of production and consumption (Kitilu, 2011). It is a major source of income, food and employment in rural areas, providing about 95% of the national food requirements and livelihood to more than 70% of the Tanzanian population (MAFC, 2009). Rice accounted for 25.7% of the GDP and 22% of foreign exchange earnings in the year 2008 (MAFC, 2009).The major paddy growing regions include Shinyanga, Morogoro, Mbeya, Mwanza and Rukwa. Paddy is also not uncommon crop in the regions of Kilimanjaro, Manyara, Arusha, Dodoma, Iringa and Tanga (Kibanda, 2008). Morogoro region has been ranked second producer of rice after Shinyanga for the past five years. The importance of Morogoro region as one of the largest rice producers is attributed to the existence of the large-scale rice farms and the numerous small-scale irrigation schemes. In the year 2008, Morogoro region produced an average of 105 thousand metric tons from an estimated area of 60 thousand hectares from the following districts: Kilombero, Mvomero, Kilosa, Ulanga, Gairo and Morogoro urban with yield ranging between 1 – 2 t/ha (MAFC, 2009).

Kilombero district is predominantly rural with the semi-urban district headquarter Ifakara as major settlement. The majority of the villagers are subsistence farmers of maize and rice (Kibanda, 2001). The district contains numerous small-scale irrigation schemes and the largest commercial rice player in the country. Kilombero Plantation Limited (KPL) offers a comprehensive package of inputs, training, processing and market access to increase smallholders' yields and rice quality (BMGF, 2012).

1.2 Problem Statement and Study Justification

Domestically produced rice is acceptable due to its aromatic qualities where by excess rice can be exported to earn foreign exchange. It has been reported by MMA (2010) that the demand for quality and branded aromatic rice, primarily produced in Tanzania, from urban medium-high consumers is increasing. Likewise, most neighbouring countries do not have sufficient rice, which make the regional block a highly attractive market if efficient supply chains can be developed.

Critical weaknesses of the rice subsector are, among others, high post-harvest losses due to poor post-harvest handling and use of inefficient milling machines. USAID-COMPETE (2010) reported that the quality of the milled rice is very poor in Tanzania. Consequently, farmers incur a greater loss of the valuable rice grain than necessary. In response to that, the Government under National Rice Development Strategy (NRDS) and stakeholders in rice sub-sector have embarked on improving rice production through better farmer access to improved varieties, post-harvest technologies and enhancing agro-processing and value addition (MAFC, 2009). From economic point of view, the quality of milled rice is of paramount importance since the grain size and shape, whiteness and cleanliness are strongly correlated with the transaction price of rice (Iguaz *et al.*, 2006). Rice is normally priced above maize, reflecting its superior position in the local market. Rice prices in main urban centres range from 700 and can go beyond 2000 TZS/kg depending on demand/supply balances (MMA, 2010).

Several studies on postharvest losses and rice milling quality have been done in the country (Lyinda and Tony, 2000; RLDC, 2009; USAID-COMPETE, 2010; MMA, 2010 and BMGF, 2012). While these studies are insufficient to improve the quality of the milled rice, little is known of the effect of paddy milling conditions such as final moisture content, cooling time and paddy variety on quality of milled rice. Since new and promising paddy varieties are emerging, 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 Kilombero district.

This study therefore provides preliminary information regarding the extent of variability in rice milling quality with respect to moisture content, varieties and cooling time, which save as benchmark for breeders, researchers, farmers, processors and all stakeholders in the rice industry. Improving the quality of milled rice will favour Tanzanian rice in the market. It is anticipated that both the public and private sector will take full advantage of the growing rice market opportunities in the region. This will lead to the development of effective and efficient sustainable supply chains which will in turn improve the economy of the country.

1.3. Objectives

1.3.1. General objective

To establish the paddy milling conditions that produce high-quality rice in Kilombero.

1.3.2. Specific objectives

i. To evaluate grain physical traits (opacity, grain sizes and shapes) of five paddy varieties

ii. To determine the effect of paddy variety on milling quality of rice in terms of TRY, HRY and whiteness.

iii. To evaluate the effect of final moisture content on milling quality of rice in terms of TRY, HRY and whiteness.

iv. To analyze the effect of cooling time on milling quality of rice in terms of TRY, HRY and whiteness.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Paddy Grain

Paddy grain basically consists of a husk or hull (18-28%) and a grain of brown rice or caryopsis (72-82%), as shown in Fig. 1. Brown rice consists of an outer layer (including pericarp, seed coat, and aleurone layer) called bran (3-6%), a germ or embryo and scutellum connected on the ventral side of the grain (2-3%), and an edible portion or endosperm (67-73%) (Pan *et al.,* 2007). Basically, paddy grain is not suitable for eating. It becomes edible only if the husk and bran are removed but it may be better in terms of nutrition, if the bran is not removed (Adil *et al.*, 2011). However, in most cases consumers prefer white rice, i.e., rice with the bran being removed, because white rice may have better smell and taste (Pan *et al.*, 2007).

The removal of the husk and the bran can be done in the milling process. However on threshing, it is important to watch at what point the paddy grain will break off its panicle, because the pedicel (the panicle bears rice spikelet, which develop into grains) should not be a part of the grain (Wenela,2013), or else it will have a reduced milled rice recovery through the increase of husk production.

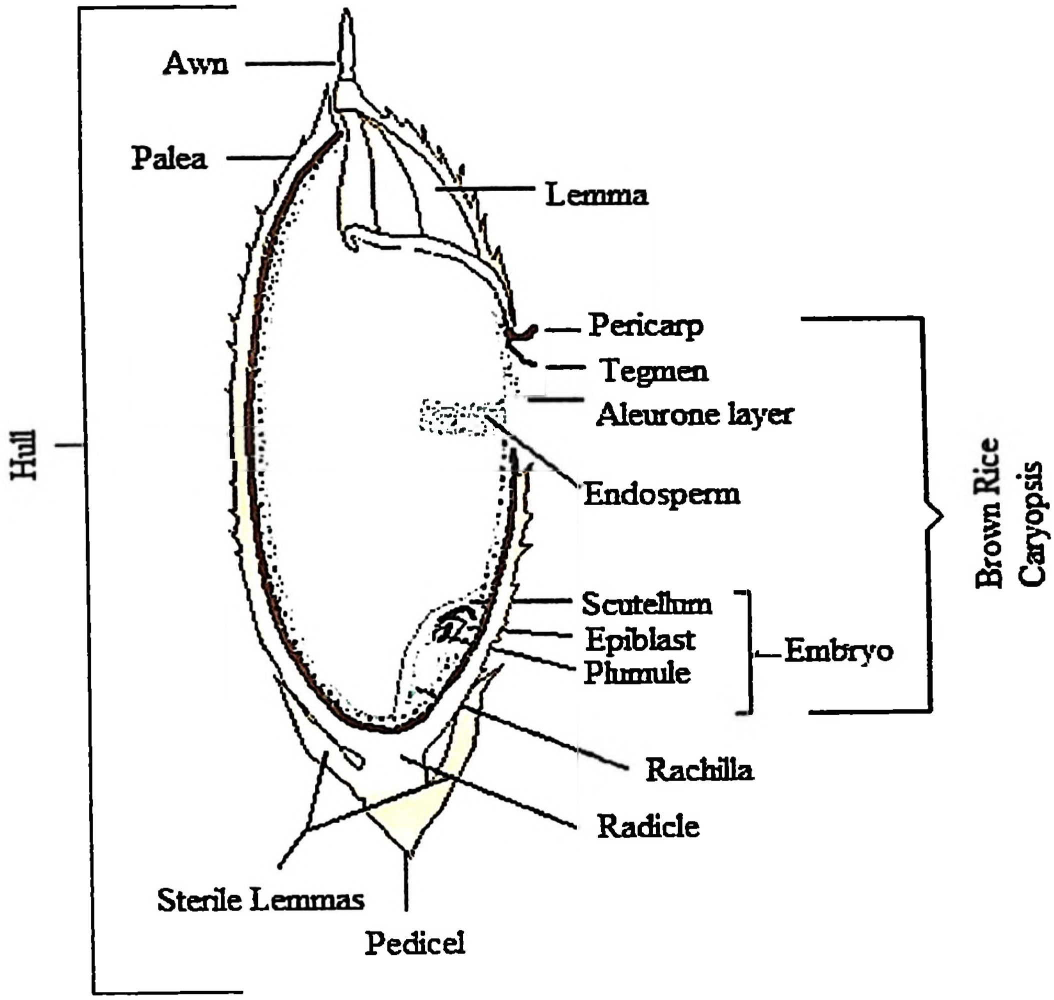


Figure 1: Longitudinal section of rice grain structure

Source: IRRI (2013a)

2.2 The Rice Milling Process and Losses During Milling

2.2.1The rice milling process

To make paddy more edible, digestible and appetizing, it has to be milled, the process which entails removal of husk layers and the germ (IRRI, 2013a). Milling, an important processing step of paddy (rough rice) is usually done to produce white and polished edible grain, according to consumer preference i.e. rice that is sufficiently milled, free of dockage and maximize the total milled and head rice recovery out of paddy (Wenela, 2013). A typical rice milling system is a multi-stage process where the paddy is first subjected to dehusking by using a sheller followed by removal of brown outer layer known as whitening (Alizadeh *et al.*, 2011). Output of a milling process comprises one main product, i.e., milled rice (or the edible portion) and several by-products, i.e., the husk, the germ, the bran layer and the broken kernels (Le, 2003). The husk can be used as an energy generating material; the germ and the bran layer can be used as good source of protein, fat/oil, dietary fibre, vitamin E and various plant sterols; the broken kernels together with the germ and the bran layer, can be used to feed animals (Kibanda, 2001).

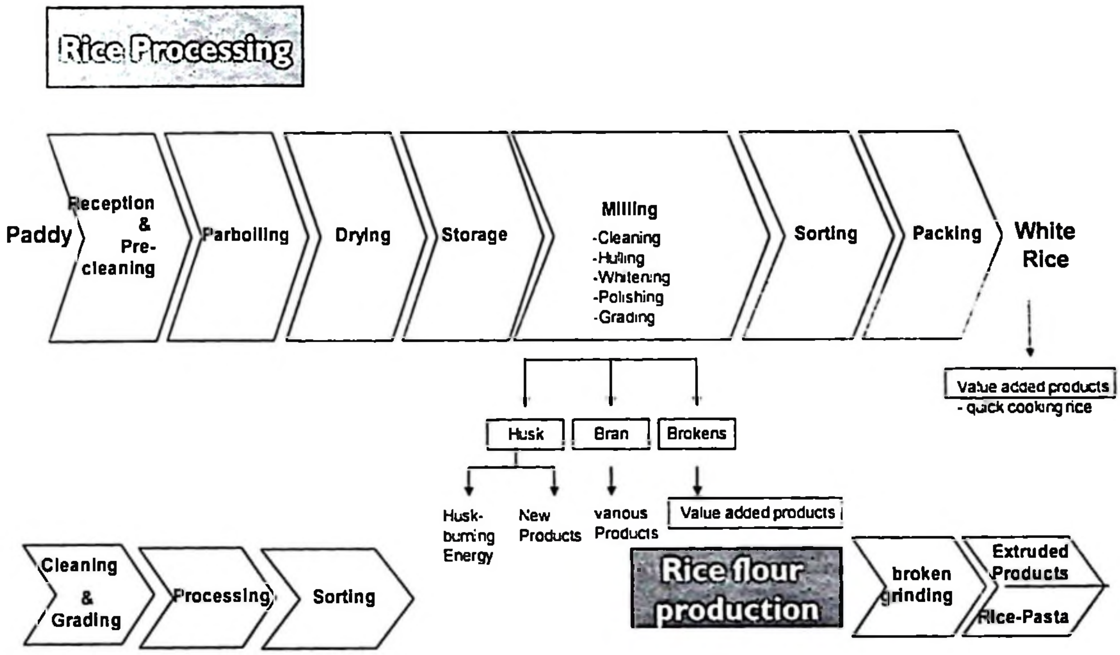


Figure 2: Rice processing chain

Source: USAID-FtF (2014)

2.2.2 Losses during milling

After harvesting and drying, the paddy is subjected to the primary milling operation which includes de-husking as well as the removal of bran layers (polishing) before it is consumed. In this process, the rice which is obtained after milling is called raw rice (Kiattisak and Thanatchai, 2011). The nutritional value and head rice recovery are reduced with the higher degree of milling or whitening. Usually, 10% by weight of brown rice is removed as bran during milling (Roy *et al.*, 2011). The proteins, fats, vitamins, and minerals are concentrated in the germ and outer layer of the starchy endosperm (Itani *et al.*, 2002) and these are removed by milling operation.

Rice milling losses may be qualitative or quantitative in nature. Quantitative or physical losses are manifested by low milling recovery rate while low head rice recovery or high percentage of broken kernel reflects the qualitative loss in rice grains (Le, 2003). In order to reduce loss in milling, the rice-milling operations, i.e., dehusking and whitening should be accomplished with care to prevent excessive breakage of the kernel and improve the recovery. The extent of losses during milling depends on many factors, such as variety and condition of rough rice such as percentage of matured grains, moisture content and drying methods (Gummer, 2009), degree of milling required, the kind of rice mill used, and the operators (Yada and Jindal, 2001). It was also reported by Siebenmorgen and Qin (2005); Roy *et al.* (2008) that size of the grain had great effect on milling recovery. Bold and short grains break less during milling than long and slender ones. Lower surface hardness facilitates breakage during milling, resulting to lower milled rice recovery and quality (Roy, 2003; Mohapatra and Bal, 2007) in the case of long grains compared to that of short grains. Mass loss and breakage are affected by cultivar, kernel shape, and thickness of aleurone layer (Liang, 2008). The flow ability of short grains through the milling chamber of friction type milling machine is higher than that of long grains. This results in lower degree of breakage during milling (FAO, 2004) and leads to production of high amount of head rice.

2.3 Rice Milling Techniques

The rice-milling process can be done using different milling techniques. Rice-milling techniques range from a simple form like pestle and mortar to very sophisticated, expensive multiple-pass milling machines (Rajkumar *et al.*, 2004). This process usually takes two to three cycles within a milling machine, depending on the required milling degree (Odogola, 2006). All these forms of milling techniques have existed; some of them have been extinguished. According to IRRI (2013a) four general categories of rice mills are used in most rice -producing countries; hand milling, single machine mills, two stage machine mills and multiple pass rice mills.

2.3.1 Pestle and mortar/ hand milling

This process is a manual form of milling. Mortar and pestle (Fig. 3a) are used by farmers and usually operated by female members of the family. In this process, the milling is done through the impact and friction acting among the paddy kernels. The grain is dehusked and whitened every time when it is pounded in the mortar by the pestle (IRRI, 2013a). This process is highly inefficient for two main reasons (Le, 2003); first, it is very laborious and time-consuming; second, the excessive impact and pressure result in high breakage of milled rice (qualitative loss).

Figure 3a: Milling techniques- mortar and pestle (a) and Engleberg mill (b)
Source: IRRI (2013a)

2.3.2 Single-machine mills (steel huller)

Small-capacity single -machine rice mills are often located in villages where they custom-mill for paddy producers. Their capacities range from 45 to 270kg of paddy/h, having low white rice recovery of 50-55% and head rice less than 30% (Yada and Jindal, 2001; IRRI, 2013a). Single-machine mills are manual or powered by electric motors, diesel engines, or tractors (Le, 2003).

Steel hullers also referred to as Engleberg steel hullers (Fig. 3a), are more efficient than pestle and mortar. A rotating steel roller inside a screen cylinder provides pressure and friction among the grains, simultaneously dehusking and polishing of the kernels (Le, 2003).Steel huller consists of two horizontal iron discs partly coated with abrasive layers. One disc is stationary and the other rotates. The distance between the two disks can be adjusted to suit the size of paddy grain. Paddy is fed into the hopper and is evenly distributed over the surface of the rotating disc. Under the centrifugal pressure and friction of the disc, most of the paddy grains are dehusked (Yada and Jindal, 2001).

The main advantage of steel shellers is its operational simplicity and low running cost since the abrasive coating can easily be remade at the site with inexpensive materials. Its main disadvantage is the high level of grain breakage and the abrasions caused to the outer bran layer (Le, 2003).

2.3.3 Two step-machine mills (Super seeded Engleberg (steel) mill)

Super seeded Engleberg (steel) mill has separate hulling (dehusking) and whitening (polisher), in which dehusking is done by rubber roller huller and whitening by steel friction polisher, with a capacity of 0.5-2.3 t /h and milling recovery of 60% (IRRI, 2013a). Compared to disc shellers, Super seeded Engleberg (steel) mills (Fig. 3b) are at an advantage in the sense that they reduce grain breakage and the risk of damaging the grain (Le, 2003), they do not remove the germ, and hence sieving the resulting rice is not necessary (Yada and Jindal, 2001) and their hulling efficiency is high. The main disadvantage is the cost of replacing the rubber rolls (Le, 2003); this disadvantage is offset, however, by the reduction of breakage and the increase of total rice overturn.

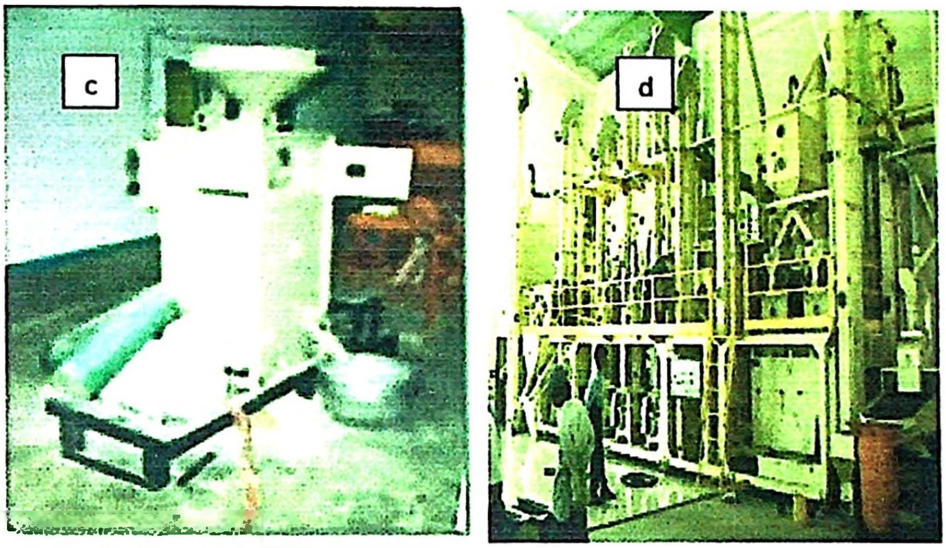


Figure 3b: Milling techniques- two stage mill (c) and multiple pass mills (d)
Source: IRRI (2013a)

2.3.4 Multiple-pass milling machines

A large capacity multiple-pass milling machine (Fig. 3b) uses different machines for each processing step (IRRI, 2013a): cleaning, dehusking, separating, bran removing, and grading. These processes are integrated into one system by bucket elevators linking machine to machine to accomplish each stage of processing to the end where output in the form of polished rice comes out (Yada and Jindal, 2001). A modern multiple-pass milling machine uses about one-half to two-thirds of the electric power of a steel huller operating at the same capacity and result in much lower loss in milling (Le, 2003).

2.4 The Rice Milling Technology in Kilombero District.

The majority of rice mills are small and medium scale enterprises with installed capacity ranging between 0.5 -2.3 t/h (RLDC, 2009), though there is one large scale rice mill at Kilombero Plantation Limited (KPL) with a milling capacity of over 2.3 t/h. Small and medium scale mills fall into two categories; steel hullers and rubber roll mill. Large scale mills usually operate on the same principle as the small rubber roll mills though there is a separate machine for each unit operation and extra equipment may be added to further improve product quality (Lyinda and Tony, 2000). While the owner of the mill usually employs only 2-3 people who manage and maintain the mill (RLDC, 2009) , there are usually other 6-7 casual laborers/workers paid on commission who are present to help with the other aspects of the milling. During peak season, the number of casual workers can increase to 20 per mill. These include moving the paddy into the mill, taking the rice from the mill. filling the bags by tamping them down, and loading the trucks (MMA, 2010).

2.5 Rice Milling Quality

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). Other authors have also mentioned that milling quality is interrelated to TRY, HRY and whiteness (Ondier *et al.*, 2010; Yadav and Jindal, 2008).

2.5.1 Total Rice Yield (TRY)

Total Rice Yield (TRY) includes whole kernel (head) and all other sizes of broken kernels obtainable from specified amounts of rough rice (USDA-FGIS, 2009). The objective of rice milling is removal of hulls, bran, and germ, with minimum breakage of endosperms. Yield of total milled rice is important, and is influenced by proportion of hull and amount of fine endosperm particles (Alizandeh *et al.*, 2011).

2.5.2 Head Rice Yield (HRY)

Head rice, synonymous with "whole kernels" (USDA-FGIS, 2009) is expressed as milled grains that are 3/4 or more the original grain length, as shown in Fig. 4. 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).

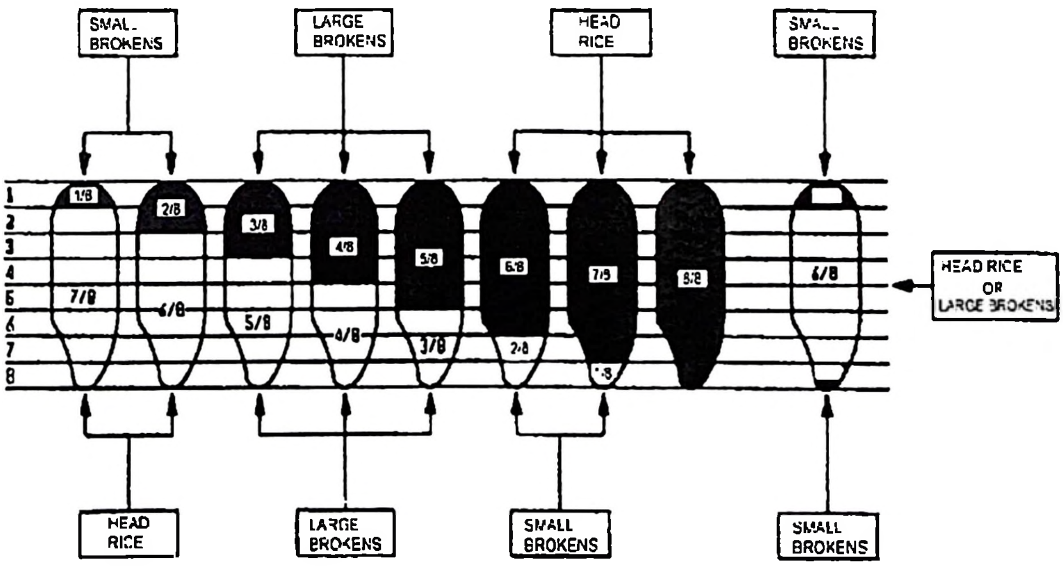


Figure 4: Interpretation of broken in milled rice

Source: USDA-FGIS (2009)

Drying and storage treatments are also known to affect rice physicochemical properties. The head rice yield is especially sensitive to the mode of drying and is usually used to assess the overall effectiveness of the drying process (Wenela, 2013). Much research has been devoted to reducing drying duration while maintaining high TRY and HRY. Lanning and Siebenmorgen (2011) reported 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.

Pearce *et al.* (2001) showed that moisture content of rice at the time of milling played a significant role in the relationship between TRY, HRY and whiteness. For a set milling duration, HRY increased as rough rice moisture content decreased. The increase in HRY was attributed to differences in whiteness. This was supported by Cooper and Siebenmorgen (2007); Bautista *et al.* (2009) whose findings showed a direct correlation between increased moisture content and whiteness. HRY also reduces with the increased duration of milling. Hence in the milling process, the pressure in the milling chamber and the duration of milling must be adjusted to get the maximum output (Alizadeh *et al.*, 2011).

2.5.3 Whiteness

Whiteness of 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, 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). A greater whiteness is invariably accompanied by increased mass loss (decreased TRY) (Grigg and Siebenmorgen, 2013) and decreased HRY (Lanning and Siebenmorgen, 2011) or conversely, milling rice to lesser degrees, that is, leaving more bran on milled kernels, can lead to greater milling yields and human nutritional benefits, as well as potential energy savings (Lanning and Siebenmorgen, 2011; Roy *et al.*, 2008). Whiteness is often dictated by consumer requirements and increases as milling progresses (Billiris *et al.*. 2012). In some countries, whiteness is not a profound index of rice quality, while Tanzanians prefer to consume rice which is white (MAFC, 2009).

2.6 Grain Physical Properties

During the milling process, different properties among rice cultivars, such as kernel topography, physical dimensions, and chemical composition, have been shown to influence milling characteristics (Siebenmorgen *et al.*, 2006). Dela and Khush (2000) found rice grain size, shapes, and translucency/chalkiness, are important contributors to general appearance and milling quality.

2.6.1 Grain size and shape

Grain size and shape are two factors contributing to the appearance of a rice grain and varies among and within varieties; however, size is more variable than grain shape, attributed to variation in lengths of the awn and the pedicel (Wenela, 2013). According to Kibanda (2001) optimal width of the rice grain is attained earlier in 14 days after flowering and the length in 4 days. Thereafter each one develops to its full size or shape but length takes longer time than width. IRRI (2013b) classified size of rice grains into four scales namely: extra long (greater than7.50mm); long (6.61 – 7.50mm); medium (5.51 – 6.60mm) and short (less than 4.50mm). Similarly, shape of rice grain is determined based on length–to–width ratio: slender (greater than 3.0); medium (2.1 – 3.0) and bold (less than 2.1).

Rice is marketed according to their grain size and shape. Each is demanded by different markets: Long-grain rice is sold mostly in Europe, USA and the Near/Middle East; medium-grain rice in the deficit countries of Asia and Africa; while short-grain product in various special-demand areas (Kibanda, 2001). Kernel dimensions are primary quality factors in most phases of processing, drying, handling equipment, grading and breeding (Lanning and Siebenmorgen, 2011); they are among the first quality characteristics considered in developing new varieties for release for commercial production. Intensive genetic selection is practiced to eliminate heritable abnormalities such as: deep creases, which tend to leave bran streaks on milling; irregularly shaped kernels; sharp-pointed extremities, which break easily during milling; and oversized germs, which detract from milling quality and grain appearance (Graham, 2002). To obtain better quality–milled rice, knowledge on paddy grain physical properties is necessary for modeling of dynamic abrasion in a rice milling operation as well as for designing suitable polishing systems (Mohapatra and Bal, 2004), as husking characteristics of paddy are dependent upon its shape and size (Shitanda *et al.*, 2001).

2.6.2 Chalkiness/Opacity

Chalkiness, a trait that is genetically inherited and environmentally influenced (especially weather) during the grain–filling period (Yamakawa *et al.*, 2007) and is related to airspace of the endosperm (Kibanda, 2001). Previous study by Cooper *et al.* (2008) showed that increasing night-time air temperatures during kernel reproductive stages dramatically increases chalkiness in several cultivars. According to 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.

If part of the milled rice kernel is opaque rather than translucent, it is often characterized as "chalky" (Wenela, 2013), referred to as 'white belly,' or 'immature,' depending on its location on or within the endosperm. Close visual examination is mostly used for determining type and amount of chalkiness (Dela and Khush, 2000). IRRI (2013b) classified percentage of chalkiness of rice grains into four scales namely: none (0%), small (less than 10 %), medium (11 – 20%) and large (more than 20%).

Chalkiness in rice kernels is an undesirable characteristic because it degrades the visual appearance, milling, cooking and processing quality of milled rice. It usually results in lower milling yields, since 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). Excessive chalkiness is undesirable for many processed products because of non uniformity produced by over processing chalky kernels under usual processing conditions (Graham, 2002).

2.7 Economic Importance of Rice

Rice is basically grown for its grain. Rice with various amylose-amylopectin rations are used in specific rice products and grain in different regions of the world (Gummer, 2009). Milled rice is mainly used as food. Its starch may be used for brewing. Waxy rice is also used for sweets, desserts and salad dressings. In Tanzania, broken rice is milled into flour mainly used for buns, doughnuts known as "*vitumbua*", bread known as "*mkate wa kumimina*"and brewing (Kibanda, 2001). Rice husks are used for livestock bedding, farm mulching, and source of fuel (Adil *et al.*, 2011). The intermediate amylose rice is used largely for fermented rice cakes in the Philippines and in canned soup in the United States of America (Kibanda, 2001). Rice straw and rice hulls are used as fertilizers. Bran and polish, and bran oil and other products provide good quality proteins, source of vitamin B; and are rich in phytin, silica, dietary fibre, trypsin inhibitor and lectin (Mejia, 2002).

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 The Study Area

The study area was Kilombero district in Morogoro Region, South Western Tanzania. It is located at an elevation of 208 meters above sea level and its coordinates are 8°15'0"North and 360°25'0"East in DMS (Degrees Minutes Seconds). The district is situated in a vast floodplain, between the Kilombero River in the south-east and the Udzungwa-Mountains in the north-west (Corti *et al*., 2000). It consists of two major growing ecosystems; irrigated and lowland rainfed. Each ecosystem has its own potential for rice production. However, rainfed lowland ecosystem produces the least while irrigated gives the most abundant rice production due to their different amount of water and the associated management (Kibanda, 2001).

3.2 Sample Size and Sampling Procedure

Purposive sampling procedure was employed in this study. Five paddy varieties TXD 88, TXD 306, SUPA, IRRITA 1 (Komboka) and IRRITA 2 (Tai) samples were purposively selected 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 new 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.

3.3 Growing Site and Crop Husbandry

Seeds of the 5 paddy varieties were purchased from ARI-KATRIN (agricultural research institute) at Ifakara town in Kilombero district and grown at Mkula village irrigation scheme. The seeds were sown on nurseries, after 10-14 days were transplanted to prepared field plots and planted at a spacing of 20cm x 20cm. The field was disc ploughed and harrowed followed by experimental plots layout (Completely Randomized Design -2 replications). Nitrogen fertilizer at 80kg 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 were done where necessary. No data was collected in the field. Experimental plots layout are on Appendix 1.

3.4 Harvesting and Postharvest Handling

SUPA, IRRITA 1 and IRRITA 2 were harvested by cutting straws 15-25 cm above ground level, using sickle 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, when 85% of the grains matured (AfricaRice, 2013). Threshing was done by beating panicles with wood/stick on tarpaulin sheet followed by traditional winnowing. Open-sun drying regime was employed where each paddy sample (TXD 88, TXD 306; IRRITA 1, IRRITA 2 and SUPA) was thin-layer spread 1 cm on tarpaulin, hand raked after 20 minutes until it attains all the five desired moisture levels (9-9.5%; 10.5 – 11%; 12-12.5%; 13.5 – 14%; 15-15.5%) as described by Kobra *et al.* (2010). Ambient temperature and relative humidity were recorded during drying. Moisture content was determined by

Superpro Moisture analyser method (Grinder Crusher Type, Supertech Agroline, Denmark). Although prelimary experiments indicated that the latter method provided higher readings compared to Oven drying method (Reference method). the two methods were highly correlated (Appendix 2). All samples were shady-cooled at ambient temperature (27.20 – 35.10^{0}C) and relative humidity (36.40 –72.10%), as shown on appendix 3, before milling at five different cooling time levels (0h; 6h; 12h; 18h; 24h).

3.5 Experimental Design

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

3.6 Measurements

3.6.1 Grain dimensions and chalkiness

About 50g of each of the five paddy varieties were sent to AfricaRice Grain Laboratory, (Cotonou, Benin). Grain dimensions (length and width) and chalkiness were estimated using the Rice Statistic Analyzer, (S21, LKL Technologia, Brazil). The data were assessed according to the scale established by the Standard Evaluation System for Rice (IRRI, 2013b) (Table 1- 3).

Table 1: Size classification

Code	Length (mm)	Grain type
1	Greater than 7.5	Extra long
3	6.61 – 7.50	Long
5	5.51 – 7.60	Medium
7	Less than 5.51	Short

Source: IRRI (2013b)

Table 2: Shape classification

Code	Length: width ratio	Grain shape
1	Greater than 3.0	Slender
5	2.1 – 3.0	Medium
9	Less than 2.1	Bold

Source: IRRI (2013b)

Table 3: Chalkiness/opacity classification

Code	% Area with chalkiness	Description
0	0	None
1	Less than 10	Small
5	11 – 20	Medium
9	More than 20	Large

Source: IRRI (2013b)

3.6.2 Total Rice Yield (TRY) and Head Rice Yield (HRY)

TRY and HRY were determined according to Graham (2002). A 100g sample was milled (dehusked and polished) using ZACCARIA laboratory mill (PAZ/1-DTA, Brazil). The milled rice sample was collected and sealed immediately, allowed to cool at ambient temperature (27.20 – 35.10°C) before being weighed to obtain a direct TRY. 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. The direct TRY and HRY of rough rice were estimated based on the following formulas;

$$\text{Total rice yield (\%)} = \frac{\text{Weight of total milled rice}}{\text{Weight of rough rice}} \times 100 \quad \text{(1)}$$

$$\text{Head rice yield (\%)} = \frac{\text{Weight of head rice}}{\text{Weight of rough rice}} \times 100 \quad \text{(2)}$$

3.6.3 Whiteness

A total of 25 milled rice samples 20g each were sent at AfricaRice Grain Laboratory, Cotonou-Benin. A color meter (CR-400, Minolta Co., Ltd., Japan) was used to measure the color value of whole kernel milled rice.

3.7 Statistical Analysis

Data were analysed following analysis of variance using GenStat Discovery Edition 4. Separation of treatment means was done using Duncan multiple range tests (DMRT) at 5% level of significance. Correlations and trend comparison analysis of TRY, HRY and whiteness means was done using Microsoft Office Excel -2007.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Grain Physical Traits of Five Rice Varieties

4.1.1 Grain length (size)

The grain length of five rice varieties was recorded as shown on Table 4 and Fig. 5. 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 ($P>0.05$). The difference in length among varieties was probably due to the genetic variation. Unlike other cereals, uniformity, shape and size are considered as the first characteristics of quality in rice, as it is consumed as a whole grain. According to MAFC (2009), rice consumers in Tanzania prefer long 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). Newly developed rice varieties need to attain these characteristics, for they influence in cleaning, grading equipment, drying operations, processing and marketing (Wenela, 2013).

Table 4: The mean physical parameters of five rice varieties

	Physical properties of milled rice					
Rice variety	GL(mm) ± SE	Size*	GLWratio ± 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
IRRITA1	6.75±0.01[ab]	Long	3.12± 0.01[b]	Slender	28.68±1.61[b]	Large
IRRITA2	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, 2013b)

Means not sharing a common superscript letter in a column are significantly 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

4.1.2 Grain length: width ratio (shape)

The grain shape (length: width ratio) of the five rice varieties is as shown on Table 4 and Fig. 5. 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. A study by Wenela (2013) reported similar results for the tested variety except TXD 88, which was categorized as slender. The shape indicated highly significant difference (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). Grain size and shape are 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.

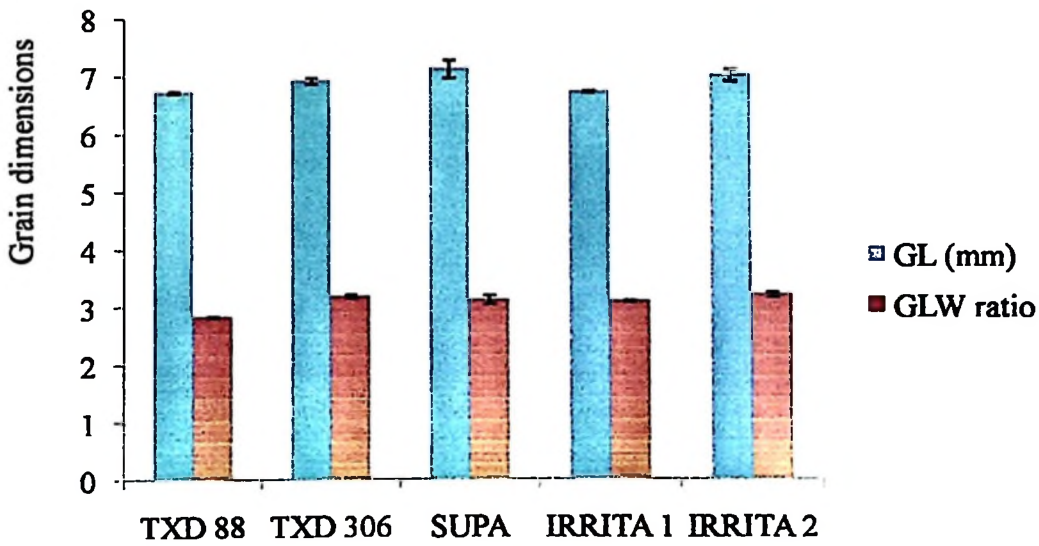


Figure 5: Grain dimensions (size and shape) of five rice varieties

(GL- Grain length, GLW- Grain length: width ratio)

4.1.3 Chalkiness (Opacity)

All five varieties described large chalkiness by the Standard Evaluation System (Table 4). Chalkiness showed highly significant difference ($P<0.05$) among tested varieties as shown on Table 4 and Fig. 6. Although TXD 306 and IRRITA 1 were not statistically different, they were statistically different ($P< 0.05$) from all the other rice varieties. Similar results were reported by Kibanda (2001) whose findings showed highest and lowest chalkiness in TXD varieties (220 and 275) and SUPA, respectively. The difference in chalkiness from 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. Paddy should be harvested when grains have an average of 20–25% moisture content, too high moisture level harvest or varieties of non uniform maturity increase chalkiness due to excessive numbers of immature kernels (Cnossen *et al.*, 2002; Graham, 2002)

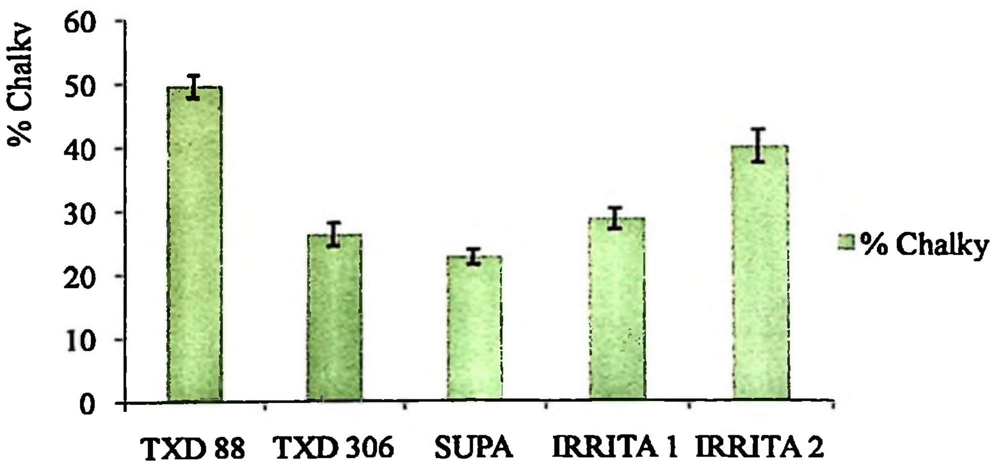


Figure 6: Chalkiness percentage of five rice varieties.

4.2 Effect of Paddy Variety on Milling Quality in Terms of TRY, HRY and Whiteness.

4.2.1 Total Rice Yield (TRY)

The rice varieties affected total rice yield of the milled rice. Milling quality in terms of TRY showed some significant differences ($P<0.05$) among rice varieties (Table 5 and Fig. 7). TXD 88 had the lowest TRY that was statistically different from all other varieties .TXD 306 and SUPA were not statistically different in TRY ($P > 0.05$), whereas IRRITA 1 and IRRITA 2 were not statistically different from each other ($P >0.05$). The variability of TRY may be related to the different behaviours of rice varieties during separation of husk from kernel, such as 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. The mechanical properties of their kernel and bran may also be different, which needs more research.

Table 5: Comparison of milling quality of five rice varieties by DMRT

	Mean values		
Rice variety	TRY ± SE	HRY ± SE	WI ± SE
TXD 88	69.05 ± 0.635^{a}	51.29 ± 1.643^{a}	70.26 ± 0.65^{c}
TXD 306	71.32 ± 0.411^{b}	60.79 ± 1.83^{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
CV	2.325	12.26	4.227
P value	<.001	<.001	0.003
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

Means not sharing a common superscript letter in a column are significant different (P< 0.05) by DMRT

4.2.2 Head Rice Yield (HRY)

The effect of variety on HRY is shown on Table 5 and Fig. 7. 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 4, Fig. 5 and 6). Previous studies by Hashemi *et al.* (2008) revealed that 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.

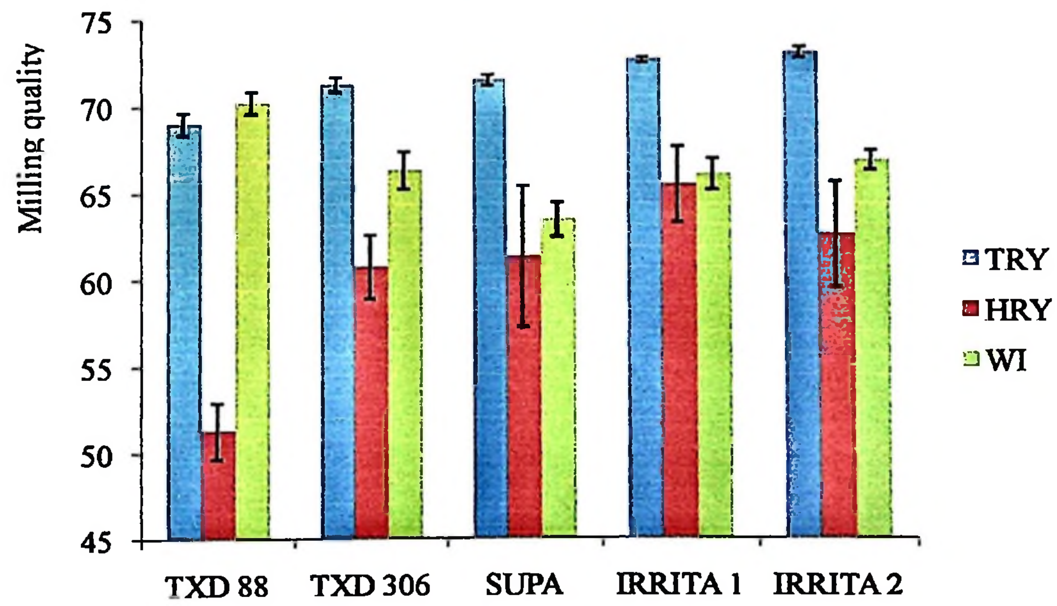


Figure 7: Milling quality in terms of TRY, HRY and WI of five rice varieties

4.2.3 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 5 and Fig. 7. This may be due to the fact that the TXD 88 had unique physical and chemical properties, such as chalkiness and shape (Table 4 and Fig. 6) that affected its whiteness. The 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.

4.3 Effect of Final Moisture Content on Milling Quality in Terms of TRY, HRY and Whiteness

Generally, final moisture content had significant ($P<0.05$) effect on milling quality showing a linear, second and third order polynomial relationship for TRY, HRY and whiteness with coefficient of determination (R^2) as shown on Fig. 8.

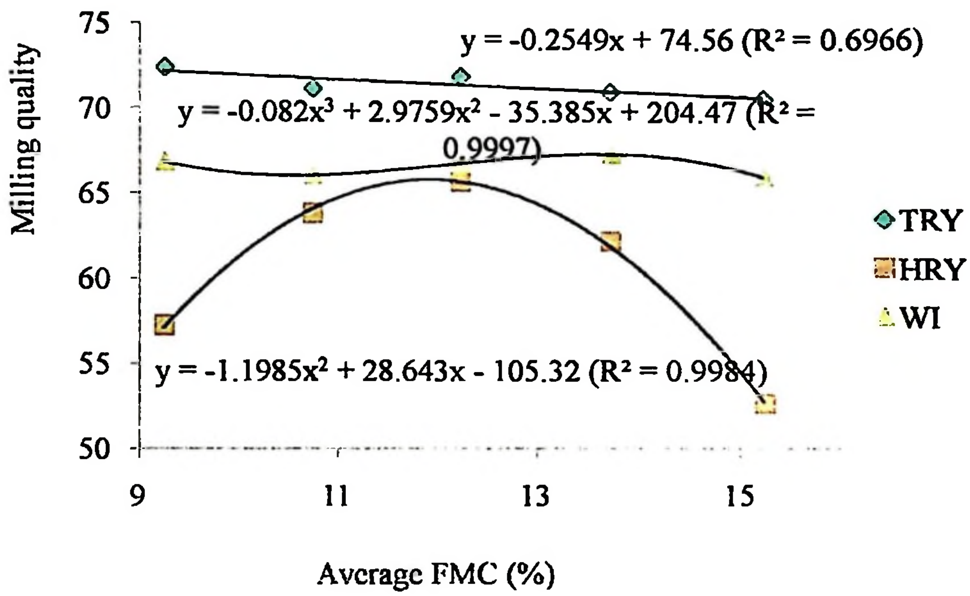


Figure 8: An estimated relationship between final moisture content and milling quality (TRY, HRY and WI)

4.3.1 Total Rice Yield (TRY)

The TRY means indicated some significant differences ($P<0.05$) among final moisture contents whereby TRY increased as final moisture content decreased from 15.5 to 9% (Table 6). 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, 2013a). However, Imoudu and Olufayo (2000) recommended 12% moisture content for achieving the highest TRY. From the results, it was observed that TRY is influenced by moisture content of paddy at milling. These results are supported by pervious researchers (Imoudu and

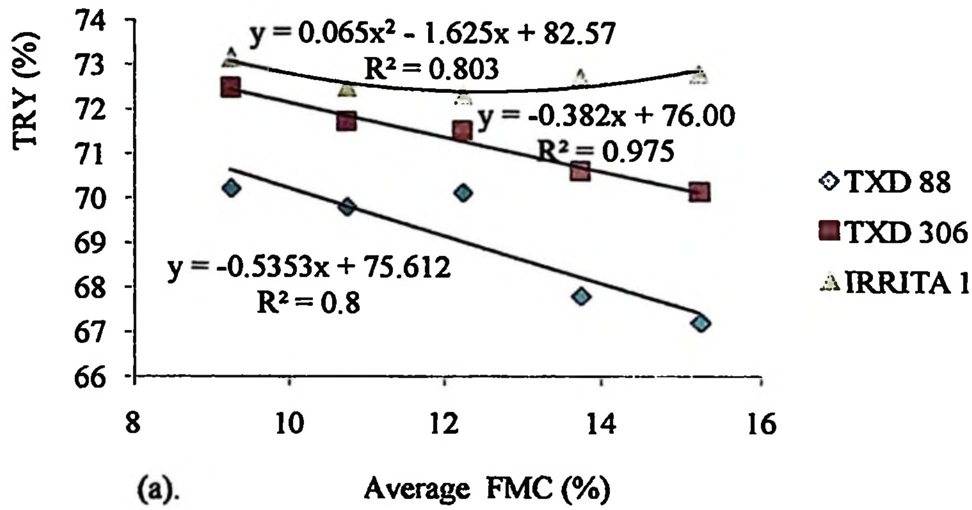
Olufayo, 2000; Miah *et al.*, 2002) who found increase in TRY with decreased moisture content for tested varieties. TRY increased with decreasing moisture content from 12 to 8%, for both parboiled and unparboiled samples of Tarom and Fajr varieties (Abozar *et al.*, 2014). With the exception of IRRITA1, final moisture content showed a linear relationship for all other varieties (TXD 88, TXD 306, SUPA and IRRITA 2) as shown on Fig. 9. IRRITA 1 showed a positive second degree trend similar but opposite to HRY trends. It is a newly released variety, thus more research need to be done to explain the trend.

Table 6: Comparison of rice milling quality for five final moisture contents by DMRT

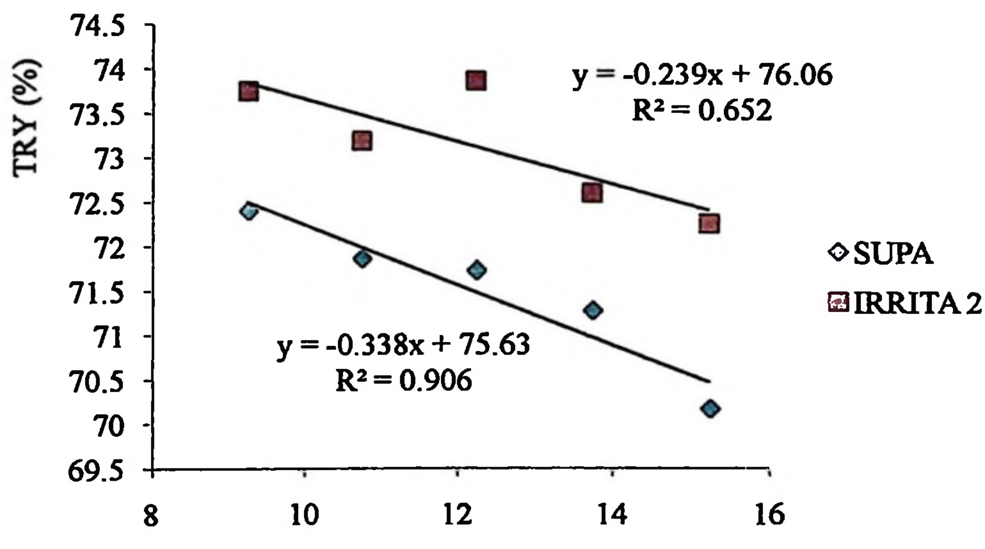
	Mean values		
FMC (%)	TRY ± SE	HRY ± SE	WI ± SE
15-15.5	70.61 ± 0.98[a]	52.63 ± 2.405[a]	66.03 ± 1.095[a]
13.5-14	71.02 ± 0.892[a]	62.21 ± 3.319[c]	67.34 ± 1.218[a]
12-12.5	71.92 ± 0.603[b]	65.70 ± 2.235[c]	66.79 ± 1.359[a]
10.5-11	71.23 ± 0.562[b]	63.83 ± 3.036[c]	66.10 ± 1.311[a]
9-9.5	72.41 ± 0.595[b]	57.22 ± 2.501[b]	66.88 ± 1.721[a]
Mean	71.56 ± 0.333	60.32 ± 1.480	66.63 ± 0.563
CV	2.325	12.26	4.227
P value	<.001	<.001	0.807
LSD	0.6501	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 are significant different (P< 0.05) by DMRT



(a).



(b).

Figure 9: An estimated TRY response of five tested rice varieties showing a linear and nonlinear relationship

4.3.2 Head Rice Yield (HRY)

HRY showed some significant differences ($P<0.05$) in final moisture content of tested varieties (Table 6), No significant differences in HRY were observed for samples with final moisture content between 10.5 – 14%. These samples were significantly different from higher (15-15.5%) and lower (9-9.5%) final moisture content. This is because a state transition into the rubbery region happens during extended drying from 10.5 to 9% final moisture content, thus resulting into HRY reduction. Previous studies (Cnossen and Siebenmorgen, 2000; Cnossen and Siebenmorgen, 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. Fig. 10 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, therefore broke during milling (Fan *et al.*, 2000). In addition, too wet grains would not 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.

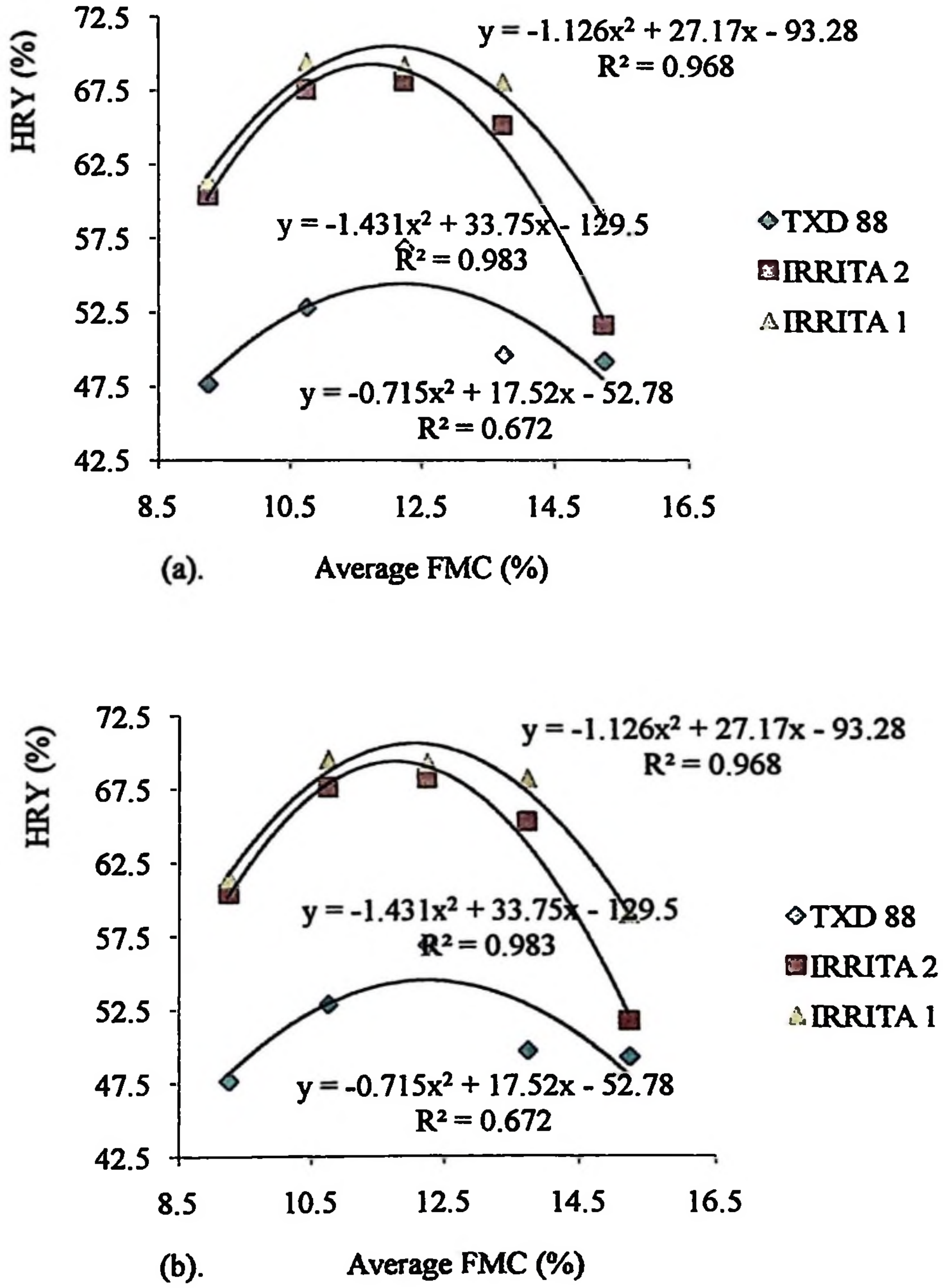


Figure 10: An estimated HRY responses of five tested rice varieties showing a nonlinear relationship

4.3.3 Whiteness

Final moisture content had no significant effect (P>0.05) on whiteness index (Table 6), showing a third order quadratic trend (Fig. 8). 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 may be due to variety used. Abozar *et al.* (2014) used only two varieties, Taron and Fajr, which were different from the five tested rice varieties.

4.4 Effect of Cooling Time on Milling Quality of Rice in Terms of TRY, HRY and Whiteness

4.4.1 Total Rice Yield (TRY)

The effect of cooling time on the values of Total Rice Yield (TRY) for the tested varieties is presented in Table 7. 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 (Fig. 11). This may be attributed to the fact that the cooling time from 0-24h 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 and Siebenmorgen, 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 was closer to immediate cooling temperature and the cooling time from 0-24h was not sufficient to develop grain fissures.

Table 7: Comparison of rice milling quality of five cooling times by DMRT

	Mean values		
Cooling time (h)	TRY ± SE	HRY ± SE	WI ± SE
0	71.17 ± 1.108[a]	61.58 ± 3.525[a]	66.38 ± 1.233[a]
6	71.33 ± 0.919[a]	59.42 ± 3.731[a]	66.88 ± 1.36[a]
12	71.94 ± 0.483[a]	60.51 ± 1.411[a]	67.10 ± 0.946[a]
18	71.89 ± 0.741[a]	58.64 ± 4.337[a]	65.02 ± 1.589[a]
24	71.44 ± 0.59[a]	61.64 ± 4.075[a]	67.75 ± 1.298[a]
Mean	71.56 ± 0.333	60.32 ± 1.480	66.63 ± 0.563
CV	2.325	12.26	4.227
P value	0.083	0.507	0.309
LSD	0.6501	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

Means not sharing a common superscript letter in a column are significant different (P< 0.05) by DMRT

4.4.2 Head Rice Yield (HRY)

The effect of cooling time on head rice yield (HRY) for the tested varieties is presented in Table 7. HRY did not significantly differ (P>0.05) by shade-cooling time at ambient temperature (27.2– 35.1°C). It shows a second order quadratic trend (Fig. 11). It may be attributed to the short cooling time (0-24h) which might have been insufficient to develop grain fissures and the sun-drying temperature was closer to immediate cooling temperature. According to Hashemi *et al.* (2008) time after drying (probably shade cooling at ambient temperature) is required before fissures developed, most kernels fissured within 48h after drying but additional fissures developed at a slower rate for another 72h thereafter. 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 24h after drying, regardless of the drying temperature and variety, are completely formed by 48h.

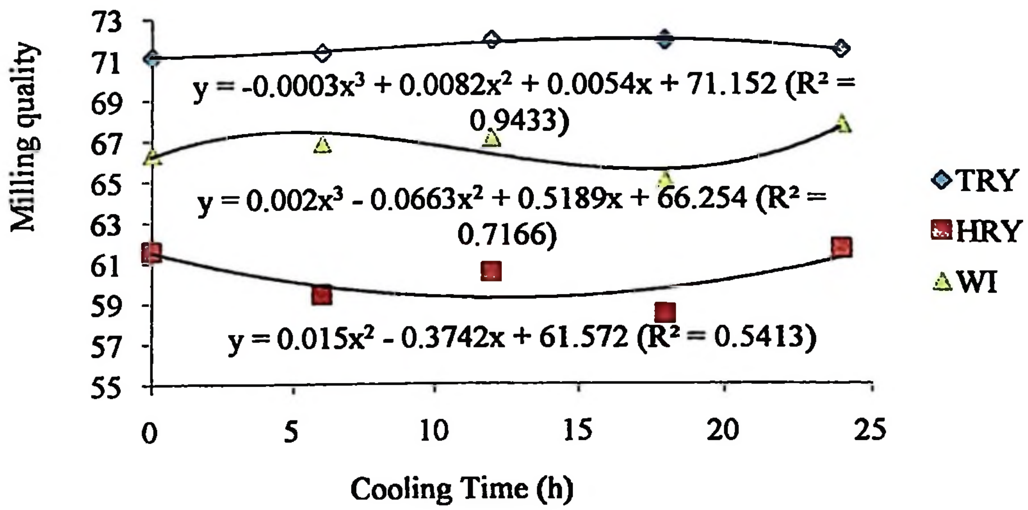


Figure 11: An estimated nonlinear relationship between cooling time and milling quality (TRY, HRY and WI)

4.4.3 Whiteness

The effect of cooling time on the degree of milling or whiteness mean values for the tested varieties is presented in Table 7. Shade cooling time at ambient temperature (27.2– 35.1°C) had no significant effect on whiteness (P>0.05). It shows a third order quadratic trend (Fig. 11). 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 as measured with a milling meter (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.

CHAPTER FIVE

5.0 CONCLUSIONS AND RECOMENDATIONS

5.1 Conclusions

The effects of final moisture content and different cooling time of paddy on milling quality parameters of five rice varieties TXD 88, TXD 306, SUPA, IRRITA 1 and IRRITA 2 were investigated through TRY and HRY percentage; and whiteness index. 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 of the grains and vice versa.

TRY showed not only variability, but an increasing trend as final moisture content decreased from 15.5 to 9 % 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 - 12.5% and 10.5 – 14% 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 – 14% for effective milling. Whiteness was not significantly affected by final moisture content.

Findings also indicate that the cooling time from 0 to 24h at ambient temperature (27.2– 35.1°C) and relative humidity (36.40 – 72.10 %) had no significant effect on quality of the milled rice tested (TRY, HRY and whiteness). This finding holds 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.

The findings give information on factors to be considered when evaluating the quality of milled rice. This information saves as benchmark for breeders, researchers, farmers, processors, administrators, policy makers and all stakeholders in the rice industry. Improving the quality of milled rice will favour Tanzanian rice in the market. It is anticipated that both the public and private sector will take full advantage of the growing rice market opportunities in the region. This will lead to the development of effective and efficient sustainable supply chains which will in turn improve the economy of the country.

5.2 Recommendations

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.

REFERENCES

Abozar, N., Bagher E., Mohammad, H. A. and Hamid, A. (2014). Influence of moisture content, variety and parboiling on milling quality of rice grains. *Journal of Rice Science* 21(2):116–122.

Adil, A., Shahzad, M., Faiza, A., Ayesha, K., Shakeela, R. and Sumera, N. (2011). Effect of processing on nutritional value of rice (*Oryza sativa*). *World Journal of Medical Sciences* 6 (2): 68-73.

Africa Rice (2013). Rice Postharvest Loss Assessment Manual. Cottonou, Benin. 48pp.

Alizandeh, M. R. and Rahmati, M. H. (2011). Effect of paddy dehusking rate in rubber roll sheller on the milling quality of different rice varieties. *Research Journal of Biological Sciences* 6(4); 153-157.

ASA (2013). Rice Seed Data: Total Quantity of Seeds (MT) Sold Crop Season 2011/12 Report. Morogoro, Tanzania. 10pp.

Bautista, R. C., Siebenmorgen, T. J. and Mauromoustakos, A. (2009). The role of rice individual kernel moisture content distributions at harvest on milling quality. *American Society of Agricultural and Biological Engineers* 52(5): 1611-1620.

Billiris, M. A., Siebenmorgen, T. J., Meullenet, J. F. and Mauromoustakos. A. (2012). Rice degree of milling effects on hydration, texture, sensory and energy characteristics. Part 1. cooking using excess water. *Journal of Food Engineering* 113: 559–568.

BMGF (2012). Developing the rice industry in Africa; Tanzania assessment. [http:// www.inter-reseaux.org/IMG/pdf/20120803_Tanzania_rice_value_chain _analysis_external_.pdf] site visited on 19/6/2013.

Bryant, R. J and McMclung, A. M. (2011). Volatile profiles of aromatic and non-aromatic rice cultivars using SPME/GC–MS. *Journal of Food Chemistry* 124: 501–513.

Campbell, R., Schiff, H., Snodgrass, D., Downing, J. and Sturza, D. (2009). *Global Food Security Response: West Africa Rice Value Chain Analysis.* USAID micro-REPORT # 161. Washington, DC. 75pp.

Cnossen, A. G. and Siebenmorgen, T. J. (2000). The glass transition temperature concept in rice drying and tempering: effect on milling quality. *Journal of American Society of Agricultural and Biological Engineers* 43:1661-1667.

Cnossen, A. G., Siebenmorgen, T. J. and Yang, W. (2002). The glass transition temperature concept in rice drying and tempering: effect on drying rate. *Journal of American Society of Agricultural and Biological Engineers 45(3):579-766.*

Cooper, N. T. W. and Siebenmorgen, T. J. (2007). Correcting head rice yield for surface lipid content (degree of milling) variation. *Journal of Cereal Chemistry* 84(1):88–91.

Cooper, N. T. W., Siebenmorgen, T. J. and Counce, P. A. (2008). Effects of night time temperature during kernel development on rice physicochemical properties. *Journal of Cereal Chemistry* 85:276-282.

Corti, G., Fanning, E., Jenkins, R. and Roettcher, K. (2000). *The Kilombero River Fishery: Annual Report.* National Lottery Charities Board (UK). Society of Environmental Dar es Salaam, Tanzania. 28pp.

Dela Cruz, N. and Khush, G.S. (2000). Rice Grain quality evaluation procedures. In: *Aromatic Rices. (Edited by Singh, R.K., Singh, U.S and Khush, G.S)*, Oxford and IBH Publishing Co. Pvt. Ltd., New Delhi. pp. 15 – 28

Fan, J., Siebenmorgen, T. J. and Yang, W. (2000). A study of head rice yield reduction of long- and medium-grain rice varieties in relation to various harvest and drying conditions. *Journal of American Society of Agricultural and Biological Engineers* 43(6): 1709-1714.

FAO (2004). *International year of rice.* Proceedings of International Year of Rice: Twenty fourth FAO Regional Conference for Europe, Montpellier, France, 12 – 13 February, 2004. 20pp.

Graham, R. (2002). A Proposal for IRRI to Establish a Grain Quality and Nutrition Research Center. IRRI Discussion Paper Series No. 44. International Rice Research Institute. Los Baños, Philippines. 15pp.

Grigg, B. C. and Siebenmorgen, T. J. (2013). Impacts of thickness grading on milling yields of long-grain rice. *Journal of Applied Engineering in Agriculture* 29(4): 557-564.

Gujral, H. S., Singh, J., Sodhi, N. S. and Singh, N. (2002). Effect of milling variables on the degree of milling of unparboiled and parboiled rice. *International Journal of Food Properties* 5(1): 193–204.

Gummer, M. (2009). Improved Postharvest Technologies for Reducing Postharvest Losses and Increasing Farmers' Incomes From Their Rice Harvests: A Special Rice Seminar. Research and Development Building. Kasetsart University, Thailand. January 9, 2009. 48pp.

Hashemi, J., Haque, A., Shimizu, A. and Kimura, T. (2008). Influence of Post-drying duration on the head rice yield of aromatic rice. [http://www.cigrjourna l.org/index.php/Ejounral/article/viewFile/1218/1075] site visited on 09/02/2013

Iguaz, A., Rodríguez, M. and Vírseda, P. (2006). Influence of handling and processing of rough rice on fissures and head rice yields. *Journal of Food Engineering* 77(4): 803–809.

Imoudu, P. B. and Olufayo, A. A. (2000). The effect of sun-drying on milling yield and quality of rice. *Journal of Bio-resource and Technology* 74(3): 267–269.

IRRI (2013a). Milling/processing: rice milling. Rice knowledge bank. International Rice Research Institute [http://www.knowledgebank.irri.org/rkb/index. php/rice-milling] visited on 17/06/2013.

IRRI (2013b). Standard Evaluation System for Rice. Rice Knowledge Bank. International Rice Research Institute . [http://www.knowledge bank.irri .org/extension/index.php/ses] site visited on 10/03/2013.

Itani, T., Tamaki, M., Arai, E. and Horino, T. (2002). Distribution of amylase. nitrogen, and minerals in rice kernels with various characters. *Journal of Agriculture Food and Chemistry* 50: 5326-5332.

Karbassi, A. and Mehdizadeh, Z. (2008). Drying rough rice in a fluidized bed dryer. *Journal of Agriculture Engineering Research* 10: 233–241.

Kiattisak, B. and Thanatchai, K. (2011). Effect of Dust Particles in Local Rice Mills on Human Respiratory System. *World Academy of Science, Engineering and Technology Journal* 56: 08-26.

Kibanda, N. J. M. (2001). Effect of genotype x environment interactions on yield and grain qualities of rice (*Oryza sativa*, L) in Morogoro region. Dissertation for Award of MSc Degree at Sokoine University of Agriculture, Morogoro, Tanzania, 127pp.

Kibanda, N. J. M. (2008). Rice Research and Production in Tanzania. Paper Presented at the African Japanese Plenary Workshop on Sustainable Rice Production. Alexandria, Egypt. 23-25th August, 2008. 28pp.

Kitilu, M. J. F. (2011). Water and nitrogen uptake of upland NERICA (New Rice for Africa) as affected by water regimes and nitrogen concentrations of soil. Dissertation for Award of MSc Degree at Yamaguchi University, Japan, 53pp.

Kobra, T. T., Alizadeh, M. R., Habebe, F., Aprooz, M. and Rafee, N. (2010). The effect of drying temperature and final moisture contents of paddy on milling and cooking quality of rice in abrasive system. *Agricultural Scientific Information and Documentation Centre (ASIDC)*. Iran (Islamic Republic of). 28pp.

Lanning, S. B and Siebenmorgen, T. J. (2011). Comparison of milling characteristics of hybrid and pureline rice cultivars. *Journal of Applied Engineering in Agriculture* 27 (5): 787–795.

Le, K. N. (2003). Investment of Rice Mills in Vietnam; The Role of Financial Market Imperfections and Uncertainty. Theses for Award of PhD Degree at Groningen University, Netherlands. 224pp.

Liang, J., Li, Z., Tsuji, K., Nakano, K., Robert, M. J. N. and Robert, H. J. (2008). Milling characteristics and distribution of phytic acid and zinc in long-, medium- and short-grain rice. *Journal of Cereal Science* 48: 83-91.

Lyinda, H. and Tony, S. (2000). Postharvest practices that may affect rice milling quality in Tanzania. [http://r4d.dfid.gov.uk/PDF/Outputs/R7531-002.pdf] site visited on 21/05/2013

MAFC (2009). National Rice Development Strategy. [http://www.Rice forAfrica.org /downloads/NRDS/Tanzania.En pdf (Verified)] site visited on 15/03/2013.

Mehdizadeh, Z. and Zomorodian, A. (2009). A study of the effect of solar drying system on rice quality. *Journal of Agriculture Engineering Research* 11: 527–534.

Mejía, D. J. (2002). *An overview of rice post-harvest technology: use of small metallic silos for minimizing losses.* Proceedings of the 20th Session of the International Rice Commission, Bangkok, Thailand, 23–26 July 2002. 120pp.

Miah, M. A. K., Haque, A., Douglass, M. P. and Clarke. B. (2002). Parboiling of rice. Part I: Effect of hot soaking time on quality of milled rice. *International Journal of Food Science and Technology* 37(5): 527–537.

MMA (2010). Value analysis of rice and maize in selected districts in chain Tanzani a. Volume I: Introduction, context analysis and recommended way forward. Final report. Dar es Salaam, Tanzania. 89pp.

Mohapatra, D. and Bal, S. (2007). Effect of degree of milling on specific energy consumption, optical measurements and cooking quality of rice. *Journal of Food Engineering* 80: 119-125.

Odogola, R. W. (2006). Final survey report on the status of rice production, processing and marketing in Uganda. [http: //www.mofa.go.jp/ mofaj/ gaiko/oda/bunya/agriculture/pdf/uganda_report.pdf] site visited on 21/04/2013.

Ondier, G. O., Siebenmorgen, T. J. and Mauromoustakos, A. (2010). Low temperature, low-relative humidity drying of rough rice. *Journal of Food Engineering* 100(3): 545–550.

Pan, Z., Amaratunga, K. S. P. and Thompson, J. F. (2007). Relationship between rice sample milling conditions and milling quality. *Journal of American Society of Agricultural and Biological Engineers* 50(4): 1307–1313.

Pearce, M. D., Marks, B. P. and Meullenet, J. F. (2001). Effects of postharvest parameters on functional changes during rough rice storage. *Journal of Cereal Chemistry* 78:354-357.

Rajkumar, P., Varadharaju, N. and Sreenaryaanan, V. V. (2004). Studies on milling out turn of paddy varieties using rubber roll sheller. *Madras Agricultural Journal* 91(1-3):1-4

Razavi, S. M. A. and Farahmandfar, R. (2008). Effect of hulling and milling on the physical properties of rice grains. *International Journal of Agro-physics* 22: 353–359.

RLDC (2009). Rice sector strategy; improving rice profitability through increased productivity and better marketing focusing on Tanzania's central corridor. [http:/ /www.rldp .org/downloads/rice_strategy.pdf] site visited on 23/06/2013.

Roy, P. (2003). Improvement of Energy Requirement in Traditional Parboiling Process. Dissertation for Award of PhD Degree at University of Tsukuba, Ibaraki, Japan, 169pp.

Roy, P., Ijiri, T., Okadome, H., Nei, D., Orikasa, T., Nakamura, N. and Shiina, T. (2008). Effect of processing conditions on overall energy consumption and quality of rice (*Oryza sativa L.*). *Journal of Food Engineering* 89 (3): 343–348.

Roy, P., Orikasa, T., Okadome, H., Nakamura, N. and Shiina, T. (2011). Processing conditions, rice properties, health and environment. *International Journal of Environmental Research and Public Health* 8: 1957-1976

Shitanda, D., Nishiyama, Y. and Koide, S. (2001). Performance analysis of an impeller husker considering the physical and mechanical properties of paddy rice. *Journal of Agriculture Engineering* 79: 195–203

Siebenmorgen, T. J. and Qin, G. (2005). Relating rice kernel breaking force distributions to milling quality. *American Society of Agricultural and Biological Engineers* 48: 223-228.

Siebenmorgen, T. J., Bautista, R. C. and Counce, P. A. (2007). Optimal harvest moisture contents for maximizing milling quality of long- and medium grain rice cultivars. *Journal of Applied Engineering in Agriculture* 23(4):517-527.

Siebenmorgen, T. J., Counce, P.A. and Wilson, Jr. C.E. (2014). Factors Affecting Rice Milling Quality. Agriculture and Natural Resources. FSA2164. [http://www.uaex.edu/publications/PDF/FSA-2164.pdf] visited on 30/03/2014.

Siebenmorgen, T. J., Matsler, A. L. and Earp, C. F. (2006). Milling characteristics of rice cultivar and hybrids. *Journal of Cereal Chemistry* 83(2): 169-172.

Siebenmorgen, T. J., Qin, G. and Jia, C. (2005). Influence of drying on rice fissure formation rates and mechanical strength distributions. *American Society of Agricultural and Biological Engineers* 48: 1835-1841.

USAID-COMPETE (2010). Staple Foods Value Chain Analysis Country Report-Tanzania. [http://www.competeafrica.org/Files/Tanzania_Staple_Foods_Value_Chain_Analysis_Study_JUNE_2010.pdf] site visited on 28/06/2013.

USAID-FtF (2014). Technologies and techniques for improving quality, volume and cost in Tanzania. Workshop on Best Global Practices for Rice Processing. Morogoro, Tanzania. April 03 – 04, 2014. 21pp.

USDA-FGIS (2009). *United States standards for rice.* Federal Grain Inspection Service. Washington, D.C, US, 37pp.

Wenela, J. (2013). Quality and acceptability of new rice varieties (*Oryza sativa L.*) in Kilombero district, Morogoro Tanzania. Dissertation for Award of MSc Degree at Sokoine University of Agriculture, Morogoro, Tanzania, 115 pp.

Yadav, B. K. and Jindal, V. K. (2001). Monitoring milling quality of rice by image analysis. *Computers and Electronics in Agriculture Journal* 33: 19–33.

Yadav, B. K. and Jindal, V. K. (2008). Changes in head rice yield and whiteness during milling of rough rice (*Oryza sativa L.*). *Journal of Food Engineering* 86(1): 113–121.

Yamakawa, H., Hirose, T., Kuroda, M. and Yamaguchi, T. (2007). Comprehensive expression profiling of rice grain filling-related genes under high temperature using DNA microarray. *Journal of Plant Physiology* 144: 258-277.

Yan, T. Y., Hong, J. H. and Chung, J. H. (2005). An improved method for the production of white rice with embryo in a vertical mill. *Iranian Journal of Biosystems Engineering* 92(3): 317–323.

APPENDICES

Appendix 1: Experimental plots layout and Latin Square Design (LSD) layout

Experimental plots layout

Rep. I	A	B	C	D	E
Rep. II	C	D	E	A	B

Where: A,B,C,D,E are different paddy varieties, for TXD 88, TXD 306, SUPA, IRRITA 1 and IRRITA 2 respectively

Latin Square Design (LSD) layout

	Final Moisture Content, % (Column)				
Cooling time, h (Row)	I	II	III	IV	V
0	A	B	C	D	E
6	E	A	B	C	D
12	D	E	A	B	C
18	C	D	E	A	B
24	B	C	D	E	A

Where;

I. = Final moisture content at 15-15.5%

II. = Final moisture content at 13.5-14%

III. = Final moisture content at 12-12.5%

IV. = Final moisture content at 10.5-11%

V. = Final Moisture Content at 9-9.5%

A,B,C,D,E = Different paddy variety treatment outcomes/ responses (TRY %, HRY %, whiteness Index) of TXD 88, TXD 306, SUPA, IRRITA 1 and IRRITA 2 respectively

Appendix 2: Pre-test moisture content analysis

Descriptive statistics

	N	Minimum	Maximum	Mean	Std. Deviation
Superpro MC	75	10.00	14.40	12.3667	.95370
Oven MC	75	8.16	13.02	10.8371	1.13430
Valid N (listwise)	75				

Correlations

		Superpro MC	Oven MC
Superpro MC	Pearson Correlation	1	.968**
	Sig. (1-tailed)		.000
	N	75	75
Oven MC	Pearson Correlation	.968**	1
	Sig. (1-tailed)	.000	
	N	75	75

**. Correlation is significant at the 0.01 level (1-tailed).

Appendix 3: Descriptive statistic: weather conditions

	Temp. °C			Rh. %		
Day	Min	Mean	Max	Min	Mean	Max
1	27.60	31.42 ± 2.5869	34.10	40.60	50.28 ± 9.3004	64.10
2	27.20	31.34 ± 2.6576	33.90	41.30	50.90 ± 11.5280	69.00
3	29.10	32.74 ± 2.4521	35.10	36.40	46.58 ± 11.4356	63.90
4	27.30	31.98 ± 2.9038	34.50	37.30	48.98 ± 14.4560	72.10
Overall:	27.20	31.87 ± 2.5033	35.10	36.40	49.19 ± 10.9818	72.10
S.E		2.655			11.82	
% CV		8.3			24.0	

Temp. = Temperature, Rh. = Relative humidity, S.E = Standard Error, % C.V = % Coefficient of Variation, Min = Minimum, Max = Maximum.

Appendix 4: Final moisture content data with respect to varieties.

Table 1: Total Rice Yield (TRY)

	Rice varieties				
FMC %	TXD 88	TXD 306	SUPA	IRRITA 1	IRRITA 2
15 – 15.5	67. 23	70.17	70.56	72.82	72.25
13.5 – 14	67.82	70.64	71.28	72.74	72.60
12 – 12.5	70.15	71.54	71.73	72.34	73.86
10.5 – 11	69.83	71.74	71.87	72.51	73.19
9 – 9.5	70.24	72.49	72.41	73.17	73.75

Table 2: Head Rice Yield (HRY)

	Rice varieties				
FMC %	TXD 88	TXD 306	SUPA	IRRITA 1	IRRITA 2
15 – 15.5	49.25	57.14	46.11	58.99	51.67
13.5 – 14	49.69	61.48	66.40	68.22	65.27
12 – 12.5	56.93	66.85	67.23	69.32	68.19
10.5 – 11	52.89	61.67	67.44	69.53	67.63
9 – 9.5	47.70	56.83	59.67	61.47	60.42

Appendix 5: Five rice varietal Analysis of Variance (ANOVA) parameter from physical properties of variance of analysis table.

Analysis of variance

Variate: Length

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	4	0.39802	0.09951	4.96	
Rep.*Units* stratum					
Treat	4	0.62378	0.15595	7.77	0.001
Residual	16	0.32106	0.02007		
Total	24	1.34286			

Least significant differences of means (5% level)

Table	Treat
rep.	5
d.f.	16
l.s.d.	0.1899

Duncan's multiple range test

Treat	Mean	
1	6.742	a
4	6.748	ab
2	6.938	ac
5	7.034	cd
3	7.144	d

Summary statistics for Length
=============================

Number of values = 25
Number of observations = 25
Number of missing values = 0
Mean = 6.921
Minimum = 6.53
Maximum = 7.33
Standard deviation = 0.237
Standard error of mean = 0.0473
Variance = 0.0560
Coefficient of variation = 3.418

Summary statistics for Length: Treat 1
======================================

Number of values = 5
Number of observations = 5
Number of missing values = 0

```
                   Mean = 6.742
     Standard deviation = 0.0295
 Standard error of mean = 0.0132
               Variance = 0.00087
```

Summary statistics for Length: Treat 2
======================================

```
       Number of values = 5
 Number of observations = 5
Number of missing values = 0
                   Mean = 6.938
     Standard deviation = 0.111
 Standard error of mean = 0.0494
               Variance = 0.0122
```

Summary statistics for Length: Treat 3
======================================

```
       Number of values = 5
 Number of observations = 5
Number of missing values = 0
                   Mean = 7.144
     Standard deviation = 0.344
 Standard error of mean = 0.154
               Variance = 0.119
```

Summary statistics for Length: Treat 4
======================================

```
       Number of values = 5
 Number of observations = 5
Number of missing values = 0
                   Mean = 6.748
     Standard deviation = 0.0311
 Standard error of mean = 0.0139
               Variance = 0.00097
```

Summary statistics for Length: Treat 5
======================================

```
       Number of values = 5
 Number of observations = 5
Number of missing values = 0
                   Mean = 7.034
     Standard deviation = 0.217
 Standard error of mean = 0.0970
               Variance = 0.0470
```

Analysis of variance

Variate: LW

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	4	0.080064	0.020016	4.75	
Rep.*Units* stratum					
Treat	4	0.460864	0.115216	27.34	<.001
Residual	16	0.067416	0.004214		
Total	24	0.608344			

Least significant differences of means (5% level)

Table	Treat
rep.	5
d.f.	16
l.s.d.	0.0870

Duncan's multiple range test

Treat	Mean	
1	2.848	a
4	3.116	b
3	3.138	bc
2	3.204	bc
5	3.228	c

Summary statistics for LW
========================

Number of values = 25
Number of observations = 25
Number of missing values = 0
Mean = 3.107
Minimum = 2.83
Maximum = 3.28
Standard deviation = 0.159
Standard error of mean = 0.0318
Variance = 0.0253
Coefficient of variation = 5.125

Summary statistics for LW: Treat 1
==================================

Number of values = 5
Number of observations = 5
Number of missing values = 0
Mean = 2.848
Standard deviation = 0.0148

```
        Standard error of mean = 0.00663
                      Variance = 0.00022


Summary statistics for LW: Treat 2
==================================

             Number of values = 5
       Number of observations = 5
     Number of missing values = 0
                         Mean = 3.204
           Standard deviation = 0.0559
       Standard error of mean = 0.0250
                     Variance = 0.00313


Summary statistics for LW: Treat 3
==================================

             Number of values = 5
       Number of observations = 5
     Number of missing values = 0
                         Mean = 3.138
           Standard deviation = 0.156
       Standard error of mean = 0.0697
                     Variance = 0.0243


Summary statistics for LW: Treat 4
==================================

             Number of values = 5
       Number of observations = 5
     Number of missing values = 0
                         Mean = 3.116
           Standard deviation = 0.0195
       Standard error of mean = 0.00872
                     Variance = 0.00038


Summary statistics for LW: Treat 5
==================================

             Number of values = 5
       Number of observations = 5
     Number of missing values = 0
                         Mean = 3.228
           Standard deviation = 0.0942
       Standard error of mean = 0.0421
                     Variance = 0.00887
```

Analysis of variance

Variate: Chalky

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	4	258.552	64.638	12.53	
Rep.*Units* stratum					
Treat	4	2475.897	618.974	119.96	<.001
Residual	16	82.556	5.160		
Total	24	2817.005			

Least significant differences of means (5% level)

Table	Treat
rep.	5
d.f.	16
l.s.d.	3.046

Duncan's multiple range test

Treat	Mean	
3	22.68	a
2	26.32	b
4	28.68	b
5	40.01	c
1	49.65	d

Summary statistics for Chalky
==============================

Number of values = 25
Number of observations = 25
Number of missing values = 0
Mean = 33.47
Minimum = 20.06
Maximum = 55.18
Standard deviation = 10.83
Standard error of mean = 2.167
Variance = 117.4
Coefficient of variation = 32.37

Summary statistics for Chalky: Treat 1
======================================

Number of values = 5
Number of observations = 5
Number of missing values = 0
Mean = 49.65
Standard error of mean = 1.808
Variance = 16.34

```
Summary statistics for Chalky: Treat 2
======================================

             Number of values = 5
       Number of observations = 5
     Number of missing values = 0
                         Mean = 26.32
       Standard error of mean = 1.786
                     Variance = 15.95


Summary statistics for Chalky: Treat 3
======================================

             Number of values = 5
       Number of observations = 5
     Number of missing values = 0
                         Mean = 22.68
       Standard error of mean = 1.181
                     Variance = 6.975


Summary statistics for Chalky: Treat 4
======================================

             Number of values = 5
       Number of observations = 5
     Number of missing values = 0
                         Mean = 28.68
       Standard error of mean = 1.610
                     Variance = 12.97


Summary statistics for Chalky: Treat 5
======================================

             Number of values = 5
       Number of observations = 5
     Number of missing values = 0
                         Mean = 40.0
       Standard error of mean = 2.571
                     Variance = 33.05
```

Appendix 6: Milling quality Analysis of Variance (ANOVA) parameter from variety treatment of variance of analysis table.

Analysis of variance

Variate: TRY %

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Row stratum	4	2.3861	0.5965	2.68	
Column stratum	4	10.6812	2.6703	11.98	
Row.Column stratum					
Treat	4	50.7043	12.6761	56.89	<.001
Residual	12	2.6739	0.2228		
Total	24	66.4455			

Least significant differences of means (5% level)

Table	Treat
rep.	5
d.f.	12
l.s.d.	0.6505

Duncan's multiple range test

Treat	Mean	
A	69.05	a
B	71.32	b
C	71.57	b
D	72.72	c
E	73.13	c

Summary statistics for TRY %
===========================

Number of values = 25
Number of observations = 25
Number of missing values = 0
Mean = 71.56
Minimum = 67.23
Maximum = 73.86
Standard deviation = 1.664
Standard error of mean = 0.333
Variance = 2.769
Coefficient of variation = 2.325

Summary statistics for TRY %: Treat A
====================================

Number of values = 5
Number of observations = 5
Number of missing values = 0
Mean = 69.05
Standard deviation = 1.419

Standard error of mean = 0.635

Variance = 2.015

Summary statistics for TRY %: Treat B
====================================

Number of values = 5
Number of observations = 5
Number of missing values = 0
Mean = 71.32
Standard deviation = 0.919
Standard error of mean = 0.411
Variance = 0.845

Summary statistics for TRY %: Treat C
====================================

Number of values = 5
Number of observations = 5
Number of missing values = 0
Mean = 71.57
Standard deviation = 0.694
Standard error of mean = 0.310
Variance = 0.481

Summary statistics for TRY %: Treat D
====================================

Number of values = 5
Number of observations = 5
Number of missing values = 0
Mean = 72.72
Standard deviation = 0.317
Standard error of mean = 0.142
Variance = 0.100

Summary statistics for TRY %: Treat E
====================================

Number of values = 5
Number of observations = 5
Number of missing values = 0
Mean = 73.13
Standard deviation = 0.703
Standard error of mean = 0.314
Variance = 0.494

Analysis of variance

Variate: HRY %

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Row stratum	4	38.36	9.59	0.88	
Column stratum	4	568.15	142.04	12.97	
Row.Column stratum					
Treat	4	575.45	143.86	13.13	<.001
Residual	12	131.44	10.95		
Total	24	1313.39			

Least significant differences of means (5% level)

Table	Treat
rep.	5
d.f.	12
l.s.d.	4.561

Duncan's multiple range test

Treat	Mean	
A	51.29	a
B	60.79	b
C	61.37	b
E	62.64	b
D	65.51	b

Summary statistics for HRY %
===========================

Number of values = 25
Number of observations = 25
Number of missing values = 0
Mean = 60.32
Minimum = 46.11
Maximum = 69.53
Standard deviation = 7.398
Standard error of mean = 1.480
Variance = 54.72
Coefficient of variation = 12.26

Summary statistics for HRY %: Treat A
====================================

Number of values = 5
Number of observations = 5
Number of missing values = 0
Mean = 51.29
Standard deviation = 3.674

```
Standard error of mean = 1.643
              Variance = 13.49

Summary statistics for HRY %: Treat B
=====================================

      Number of values = 5
Number of observations = 5
Number of missing values = 0
                  Mean = 60.79
    Standard deviation = 4.092
Standard error of mean = 1.83
              Variance = 16.74

Summary statistics for HRY %: Treat C
=====================================

      Number of values = 5
Number of observations = 5
Number of missing values = 0
                  Mean = 61.37
    Standard deviation = 9.114
Standard error of mean = 4.076
              Variance = 83.06

Summary statistics for HRY %: Treat D
=====================================

      Number of values = 5
Number of observations = 5
Number of missing values = 0
                  Mean = 65.51
    Standard deviation = 4.921
Standard error of mean = 2.201
              Variance = 24.21

Summary statistics for HRY %: Treat E
=====================================

      Number of values = 5
Number of observations = 5
Number of missing values = 0
                  Mean = 62.64
    Standard deviation = 6.854
Standard error of mean = 3.065
              Variance = 46.97
```

Analysis of variance

Variate: WHITENESS

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Row stratum	4	20.928	5.232	1.35	
Column stratum	4	6.159	1.540	0.40	
Row.Column stratum					
Treat	4	116.703	29.176	7.51	0.003
Residual	12	46.616	3.885		
Total	24	190.406			

Least significant differences of means (5% level)

Table	Treat
rep.	5
d.f.	12
l.s.d.	2.716

Duncan's multiple range test

Treat	Mean	
C	63.51	a
D	66.10	ab
B	66.36	b
E	66.91	b
A	70.26	c

Summary statistics for WHITENESS
================================

Number of values = 25
Number of observations = 25
Number of missing values = 0
Mean = 66.63
Minimum = 61.83
Maximum = 72.48
Standard deviation = 2.817
Standard error of mean = 0.563
Variance = 7.934
Coefficient of variation = 4.227

Summary statistics for WHITENESS: Treat A
===

Number of values = 5
Number of observations = 5
Number of missing values = 0
Mean = 70.26
Standard deviation = 1.454
Standard error of mean = 0.650

Variance = 2.114

Summary statistics for WHITENESS: Treat B
===

Number of values = 5
Number of observations = 5
Number of missing values = 0
Mean = 66.36
Standard deviation = 2.422
Standard error of mean = 1.083
Variance = 5.867

Summary statistics for WHITENESS: Treat C
===

Number of values = 5
Number of observations = 5
Number of missing values = 0
Mean = 63.51
Standard deviation = 2.194
Standard error of mean = 0.981
Variance = 4.815

Summary statistics for WHITENESS: Treat D
===

Number of values = 5
Number of observations = 5
Number of missing values = 0
Mean = 66.10
Standard deviation = 1.996
Standard error of mean = 0.893
Variance = 3.985

Summary statistics for WHITENESS: Treat E
===

Number of values = 5
Number of observations = 5
Number of missing values = 0
Mean = 66.91
Standard deviation = 1.282
Standard error of mean = 0.573
Variance = 1.644

Appendix 7: Milling quality Analysis of Variance (ANOVA) parameter from final moisture content treatment of variance of analysis table.

Analysis of variance

Variate: TRY %

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Row stratum	4	2.3952	0.5988	2.69	
Column stratum	4	50.7141	12.6785	56.97	
Row.Column stratum					
Treat	4	10.6666	2.6666	11.98	<.001
Residual	12	2.6707	0.2226		
Total	24	66.4466			

Least significant differences of means (5% level)

Table	Treat
rep.	5
d.f.	12
l.s.d.	0.6501

Duncan's multiple range test

Treat	Mean	
I	70.61	a
II	71.02	a
IV	71.83	b
III	71.92	b
V	72.41	b

Summary statistics for TRY %
===========================

Number of values = 25
Number of observations = 25
Number of missing values = 0
Mean = 71.56
Minimum = 67.23
Maximum = 73.86
Standard deviation = 1.664
Standard error of mean = 0.333
Variance = 2.769
Coefficient of variation = 2.325

Summary statistics for TRY %: Treat I
===================================

Number of values = 5
Number of observations = 5
Number of missing values = 0

Mean = 70.61

Standard deviation = 2.191
Standard error of mean = 0.980
Variance = 4.799

Summary statistics for TRY %: Treat II
====================================

Number of values = 5
Number of observations = 5
Number of missing values = 0
Mean = 71.02
Standard deviation = 1.994
Standard error of mean = 0.892
Variance = 3.977

Summary statistics for TRY %: Treat III
=====================================

Number of values = 5
Number of observations = 5
Number of missing values = 0
Mean = 71.92
Standard deviation = 1.348
Standard error of mean = 0.603
Variance = 1.817

Summary statistics for TRY %: Treat IV
====================================

Number of values = 5
Number of observations = 5
Number of missing values = 0
Mean = 71.83
Standard deviation = 1.257
Standard error of mean = 0.562
Variance = 1.580

Summary statistics for TRY %: Treat V
===================================

Number of values = 5
Number of observations = 5
Number of missing values = 0
Mean = 72.41
Standard deviation = 1.331
Standard error of mean = 0.595
Variance = 1.772

Analysis of variance

Variate: HRY %

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Row stratum	4	38.36	9.59	0.88	
Column stratum	4	575.45	143.86	13.13	
Row.Column stratum					
Treat	4	568.15	142.04	12.97	<.001
Residual	12	131.44	10.95		
Total	24	1313.39			

Least significant differences of means (5% level)

Table	Treat
rep.	5
d.f.	12
l.s.d.	4.561

Duncan's multiple range test

Treat	Mean	
I	52.63	a
V	57.22	b
II	62.21	c
IV	63.83	c
III	65.70	c

Summary statistics for HRY %
==========================

Number of values = 25
Number of observations = 25
Number of missing values = 0
Mean = 60.32
Minimum = 46.11
Maximum = 69.53
Standard deviation = 7.398
Standard error of mean = 1.480
Variance = 54.72
Coefficient of variation = 12.26

Summary statistics for HRY %: Treat I
==================================

Number of values = 5
Number of observations = 5
Number of missing values = 0
Mean = 52.63
Standard deviation = 5.377

```
   Standard error of mean = 2.405
                 Variance = 28.91

Summary statistics for HRY %: Treat II
=====================================

        Number of values = 5
  Number of observations = 5
Number of missing values = 0
                    Mean = 62.21
      Standard deviation = 7.422
   Standard error of mean = 3.319
                 Variance = 55.08

Summary statistics for HRY %: Treat III
======================================

        Number of values = 5
  Number of observations = 5
Number of missing values = 0
                    Mean = 65.70
      Standard deviation = 4.997
   Standard error of mean = 2.235
                 Variance = 24.97

Summary statistics for HRY %: Treat IV
=====================================

        Number of values = 5
  Number of observations = 5
Number of missing values = 0
                    Mean = 63.83
      Standard deviation = 6.788
   Standard error of mean = 3.036
                 Variance = 46.08

Summary statistics for HRY %: Treat V
====================================

        Number of values = 5
  Number of observations = 5
Number of missing values = 0
                    Mean = 57.22
      Standard deviation = 5.592
   Standard error of mean = 2.501
                 Variance = 31.27
```

Analysis of variance

Variate: WHITENESS

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Row stratum	4	20.938	5.234	1.35	
Column stratum	4	116.640	29.160	7.51	
Row.Column stratum					
Treat	4	6.164	1.541	0.40	0.807
Residual	12	46.621	3.885		
Total	24	190.363			

Least significant differences of means (5% level)

Table	Treat
rep.	5
d.f.	12
l.s.d.	2.716

Duncan's multiple range test

Treat	Mean	
I	66.03	a
IV	66.10	a
III	66.79	a
V	66.88	a
II	67.34	a

Summary statistics for WHITENESS
================================

Number of values = 25
Number of observations = 25
Number of missing values = 0
Mean = 66.63
Minimum = 61.83
Maximum = 72.48
Standard deviation = 2.816
Standard error of mean = 0.563
Variance = 7.932
Coefficient of variation = 4.227

Summary statistics for WHITENESS: Treat I
===

Number of values = 5
Number of observations = 5
Number of missing values = 0
Mean = 66.03
Standard deviation = 2.448
Standard error of mean = 1.095
Variance = 5.992

```
Summary statistics for WHITENESS: Treat II
==========================================

             Number of values = 5
       Number of observations = 5
     Number of missing values = 0
                         Mean = 67.34
           Standard deviation = 2.724
       Standard error of mean = 1.218
                     Variance = 7.420

Summary statistics for WHITENESS: Treat III
===========================================

             Number of values = 5
       Number of observations = 5
     Number of missing values = 0
                         Mean = 66.79
           Standard deviation = 3.038
       Standard error of mean = 1.359
                     Variance = 9.232

Summary statistics for WHITENESS: Treat IV
==========================================

             Number of values = 5
       Number of observations = 5
     Number of missing values = 0
                         Mean = 66.1
           Standard deviation = 2.932
       Standard error of mean = 1.311
                     Variance = 8.598

Summary statistics for WHITENESS: Treat V
=========================================

             Number of values = 5
       Number of observations = 5
     Number of missing values = 0
                         Mean = 66.88
           Standard deviation = 3.848
       Standard error of mean = 1.721
                     Variance = 14.81
```

Appendix 8: Milling quality Analysis of Variance (ANOVA) parameter from cooling time treatment of variance of analysis table.

Analysis of variance

Variate: TRY %

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Row stratum	4	50.7043	12.6761	56.89	
Column stratum	4	10.6812	2.6703	11.98	
Row.Column stratum					
Treat	4	2.3861	0.5965	2.68	0.083
Residual	12	2.6739	0.2228		
Total	24	66.4455			

Least significant differences of means (5% level)

Table	Treat
rep.	5
d.f.	12
l.s.d.	0.6505

Duncan's multiple range test

Treat	Mean	
0hr	71.17	a
6hr	71.33	a
24hr	71.44	a
18hr	71.90	a
12hr	71.94	a

Summary statistics for TRY %
==========================

Number of values = 25
Number of observations = 25
Number of missing values = 0
Mean = 71.56
Minimum = 67.23
Maximum = 73.86
Standard deviation = 1.664
Standard error of mean = 0.333
Variance = 2.769
Coefficient of variation = 2.325

Summary statistics for TRY %: Treat 0hr
====================================

Number of values = 5
Number of observations = 5
Number of missing values = 0

Mean = 71.17

Standard deviation = 2.478
Standard error of mean = 1.108
Variance = 6.143

Summary statistics for TRY %: Treat 6hr
=====================================

Number of values = 5
Number of observations = 5
Number of missing values = 0
Mean = 71.33
Standard deviation = 2.055
Standard error of mean = 0.919
Variance = 4.222

Summary statistics for TRY %: Treat 12hr
======================================

Number of values = 5
Number of observations = 5
Number of missing values = 0
Mean = 71.94
Standard deviation = 1.081
Standard error of mean = 0.483
Variance = 1.169

Summary statistics for TRY %: Treat 18hr
======================================

Number of values = 5
Number of observations = 5
Number of missing values = 0
Mean = 71.90
Standard deviation = 1.656
Standard error of mean = 0.741
Variance = 2.744

Summary statistics for TRY %: Treat 24hr
======================================

Number of values = 5
Number of observations = 5
Number of missing values = 0
Mean = 71.44
Standard deviation = 1.318
Standard error of mean = 0.590
Variance = 1.738

Analysis of variance

Variate: TRY %

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Row stratum	4	50.7043	12.6761	56.89	
Column stratum	4	10.6812	2.6703	11.98	
Row.Column stratum					
Treat	4	2.3861	0.5965	2.68	0.083
Residual	12	2.6739	0.2228		
Total	24	66.4455			

Least significant differences of means (5% level)

Table	Treat
rep.	5
d.f.	12
l.s.d.	0.6505

Duncan's multiple range test

Treat	Mean	
0hr	71.17	a
6hr	71.33	ab
24hr	71.44	ab
18hr	71.90	b
12hr	71.94	b

Summary statistics for HRY %
==========================

Number of values = 25
Number of observations = 25
Number of missing values = 0
Mean = 60.32
Minimum = 46.11
Maximum = 69.53
Standard deviation = 7.398
Standard error of mean = 1.480
Variance = 54.72
Coefficient of variation = 12.26

Summary statistics for HRY %: Treat 0hr
====================================

Number of values = 5
Number of observations = 5
Number of missing values = 0
Mean = 61.58
Standard deviation = 7.882

```
Standard error of mean = 3.525
              Variance = 62.13

Summary statistics for HRY %: Treat 6hr
=====================================

          Number of values = 5
    Number of observations = 5
  Number of missing values = 0
                      Mean = 59.42
        Standard deviation = 8.344
    Standard error of mean = 3.731
                  Variance = 69.62

Summary statistics for HRY %: Treat 12hr
======================================

          Number of values = 5
    Number of observations = 5
  Number of missing values = 0
                      Mean = 60.51
        Standard deviation = 3.156
    Standard error of mean = 1.411
                  Variance = 9.959

Summary statistics for HRY %: Treat 18hr
======================================

          Number of values = 5
    Number of observations = 5
  Number of missing values = 0
                      Mean = 58.45
        Standard deviation = 9.697
    Standard error of mean = 4.337
                  Variance = 94.03

Summary statistics for HRY %: Treat 24hr
======================================

          Number of values = 5
    Number of observations = 5
  Number of missing values = 0
                      Mean = 61.64
        Standard deviation = 9.112
    Standard error of mean = 4.075
                  Variance = 83.02
```

Analysis of variance

Variate: WHITENESS

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Row stratum	4	116.640	29.160	7.51	
Column stratum	4	6.164	1.541	0.40	
Row.Column stratum					
Treat	4	20.938	5.234	1.35	0.309
Residual	12	46.621	3.885		
Total	24	190.363			

Least significant differences of means (5% level)

Table	Treat
rep.	5
d.f.	12
l.s.d.	2.716

Duncan's multiple range test

Treat	Mean	
18hr	65.02	a
0hr	66.38	a
6hr	66.88	a
12hr	67.10	a
24hr	67.75	a

Summary statistics for WHITENESS
================================

Number of values = 25
Number of observations = 25
Number of missing values = 0
Mean = 66.63
Minimum = 61.83
Maximum = 72.48
Standard deviation = 2.816
Standard error of mean = 0.563
Variance = 7.932
Coefficient of variation = 4.227

Summary statistics for WHITENESS: Treat 0hr
==

Number of values = 5
Number of observations = 5
Number of missing values = 0
Mean = 66.38
Standard deviation = 2.757

```
        Standard error of mean = 1.233
                      Variance = 7.599


Summary statistics for WHITENESS: Treat 6hr
===========================================

             Number of values = 5
       Number of observations = 5
     Number of missing values = 0
                         Mean = 66.88
           Standard deviation = 3.041
       Standard error of mean = 1.360
                     Variance = 9.247


Summary statistics for WHITENESS: Treat 12hr
============================================

             Number of values = 5
       Number of observations = 5
     Number of missing values = 0
                         Mean = 67.1
           Standard deviation = 2.114
       Standard error of mean = 0.946
                     Variance = 4.470


Summary statistics for WHITENESS: Treat 18hr
============================================

             Number of values = 5
       Number of observations = 5
     Number of missing values = 0
                         Mean = 65.02
           Standard deviation = 3.552
       Standard error of mean = 1.589
                     Variance = 12.62


Summary statistics for WHITENESS: Treat 24hr
============================================

             Number of values = 5
       Number of observations = 5
     Number of missing values = 0
                         Mean = 67.75
           Standard deviation = 2.902
       Standard error of mean = 1.298
                     Variance = 8.421
```