CHAPTER 2 LITERATURE REVIEWS

2.1 Background of rice

Rice is seeds of the monocot plants As a cereal grain, it is the most widely consumed for a large part of the world's human population, especially in Asia. It is the grain with the second-highest worldwide production, after maize (website:en.wekipedia.org/wiki/rice, 2013). Rice is an economically important food crop with nutritional diversification and helps in poverty alleviation. Rice is ranked as the world's number one human food crop. About 90% of the world's rice is produced and consumed in Asia (Marshall and Wadsworth, 1994).

In Timor Leste, principal crops such as rice have mainly been cultivated in the low input/low output self sufficient farming system. As for the staple crop, only 33,000 tonnes of rice have been domestically produced compared to 92,000 tonnes of rice consumption, so the shortage of about 60,000 tonnes was imported in 2006/2007. The marketing quantity of domestic rice has also been limited due to providing rice for home consumption. In 2009, rice productivity increased by approximately 3.16 t/ha and rice production increased to 120,744.79 tonnes. In 2010, the productivity, however, decreased by approximately 3.09 t/ha and the rice production decreased to 112,925.40 tonnes, according to the impact of climate change in that year (Yoichi, et al, 2011).

According to increased rice consumption in Timor Leste, strategies and policy framework stated by government food security is a curious issue nowadays. However, it is not yet self–sufficient in its staple food; therefore, as a consequence, rice is currently still being imported from Vietnam and Thailand to meet the deficit. Timor–Leste has historically imported about 50,000 tonnes of rice annually since its independence in 1999. However, in 2007 and 2008, Timor–Leste imported 78,000 tonnes and 80,000 tonnes of rice,

respectively, due to late and unreliable rainfall.

Globally, the rice–consuming population is growing at 2% a year. In humid and sub–humid Asia where rice is the primary staple food, the population was expected to increase by 18% during the 1990s, and by 58% over the next 35 years. Recent projections indicate a world rice need of about 758 million tons in 2025–70% more rice than is being consumed today. In South Asia, where poverty is extensive, the needed rice is expected to double over the next 40 years. Production needs can be expected to be even higher, to provide stocks, seed and non–food uses (IRRI,1995).

2.2 Structure of rice

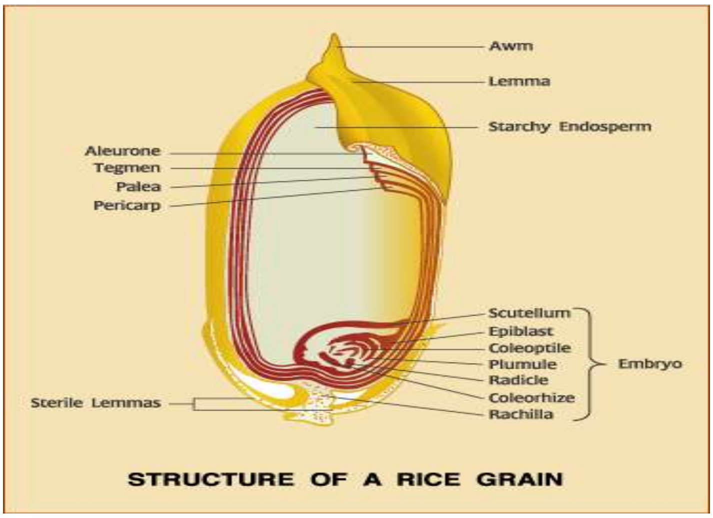

Figure 2.1 Structure of grain

Website: http://wwwteksgricemill.com/knowledstructure.htm

Rice is a covered cereal. In the threshed grain (rough rice), the kernel is enclosed in a tough siliceous hull, which renders it unsuitable for human consumption. This hull is removed during milling. The kernel (or caryopsis), composed of the pericarp (outer bran) and the seed proper (inner bran, endosperm, and germ), is known as brown rice or sometimes as unpolished rice. Brown rice is in little demand as a food. Unless stored under favorable conditions, it tends to become rancid and is more subject to insect infestation than the various forms of milled rice. When brown rice is subjected to further milling processes, the bran and germ are removed and the purified endosperms are marketed as white rice or polished rice. Milled rice is classified according to size as head rice (whole endosperm) and various classes of broken rice, known as second head, screenings, and brewer's rice, in order of decreasing rice size (Pomeranz, 1987).

The rice grain, commonly called a seed, consists of the true fruit or brown rice (caryopsis) and the hull, which encloses the brown rice. Brown rice consists mainly of the embryo and endosperm. The surface (pericarp) contains several thin layers of differentiated tissues that enclose the embryo and endosperm. The palea, lemmas, and rachilla constitute the hull that usually includes rudimentary glumes and perhaps a portion of the pedicel. The dry weight of a single grain weighs between 10 and 40 mg. The grain lengths, width, and thickness vary widely among varieties. The hull averages about 20% of the total grain weight. Grain dimensions are an important appearance quality of rice and rice entering trade is usually classified its grain size and uniformity (Chapman and Hall, 1996).

2.3 Nutritional value

The grain quality of rice is a complex character composed of many components such as nutritional quality, appearance quality, cooking quality and eating quality. Each one of these components also consists of many attributes whose values are determined not only by their physical-chemical properties, but also by the history and cultural traditions of the people in the human communities who consume the rice (Tan et al., 1999). Grain quality currently represents a major problem in rice production in Timor Leste and many other rice producing areas of the world were observed.

Table 2.1 Proximate composition of rough rice and its milling fraction at 14 % MC.

Rice fraction	Crude protein (g) (N x 5.95)	Crude fat (g)	Crude fiber (g)	Crude ash (g)	Carbohydrate (g)	Bulk density (g/ml)
Rough rice	5.8-7.7	1.5-2.3	7.2-10.4	2.9-5.2	64-73	0.56-0.64
Brown rice	7.1-8.3	1.6-2.8	0.6-1.0	1.0-1.5	73-87	0.68
Milled rice	6.3-7.1	0.3-0.5	0.2-0.5	0.3-0.8	77-89	0.78-0.85
Rice bran	11.3-14.9	15.0-19.7	7.0-11.4	6.6-9.9	34-62	0.20-0.40
Rice hull	2.0-2.8	0.3-0.8	34.5-45.9	13.2-21.0	22-34	0.10-0.16

Website : nutritionalbichem.blogspot.com/2011/08/03

2.3.1 Major rice components

2.3.1.1 Starch

Starch is the major constituent of the endosperm and makes up more than 90% of the dry matter. It is matter present essentially only in the endosperm cells of brown rice in the form of compound granules that are polyhedral due to their packing in the endosperm cells of the mature grains. Starch molecules in the granule occur in an orderly giving cristalinity to the granule in both waxy and non–waxy rices. Starch granules are fairly hygroscopic; therefore, the moisture content of the rice grain readily changes with a change in storage temperature or relative humidity. The starch granule structure is defined in terms of amorphous and semi crystalline growth rings. Starch is a partially crystalline, partially amorphous polymer of glucose. Amylose and the branching point of amylopectin contribute to the amorphous region and the outer chain of amylopectin contributes to the crystalline region (Perdon, et al., 1999).

2.3.1.2 Structure of amylose and amylopectin

Starch is made up of glucose units and occurs as two distinct fractions–a branched fraction amylopection and a linear fraction amylose. The major linkage is α–, 4–D–glucopiranocidie, but amylopectin contains, in addition, the α–1.6–D–glucopyranosidie linkage at branched points. Amylose is a roughly linear molecule containing ~ 99% α–(1–4) and ~ 1% α– (1.6) bonds with a molecular weight of ~ $1 \times 10^5 - 1 \times 10^6$. Amylopectin (molecular weight ~ $1 \times 10^7 - 1 \times 10^9$) is a much larger molecule than amylose and is heavely branched with ~ 95% α– (1–4) and ~ 5% α (1–6). Each amylose chain is of the order of 1000 glucose units long, whereas the unit chains of amylopectin range from ~ 12 to 120 anhydroglucose units (Tester, et al., 2004). The degree of branching in amylopectin is approximately one per twenty–five glucose units in the unbranched segments. The degree of branching and the side chain length vary from source to source, but in general,the more the chains are branched,the more the starch is soluble.

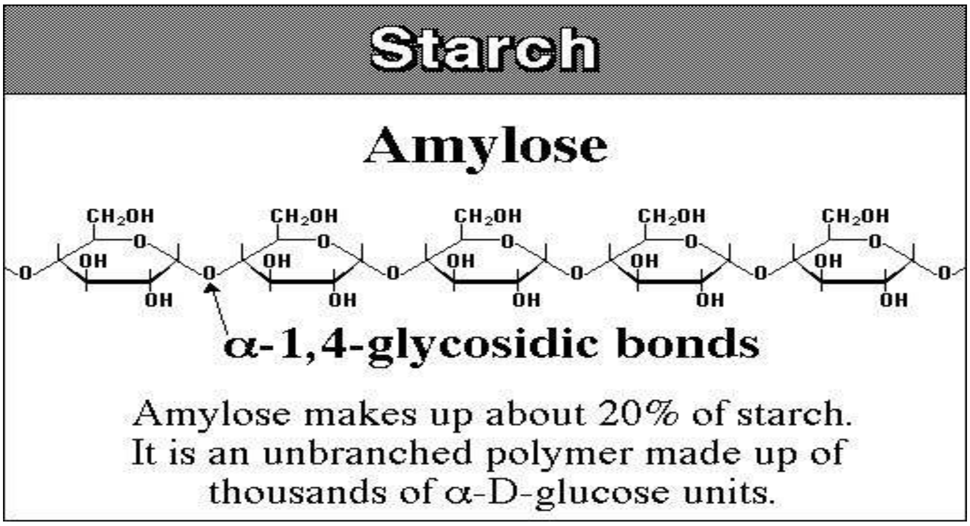

Figure 2.2 Structure of linear fraction amylose of rice starch.

(http://www.atue.edu/~nsw/ench485/lab5.htm)

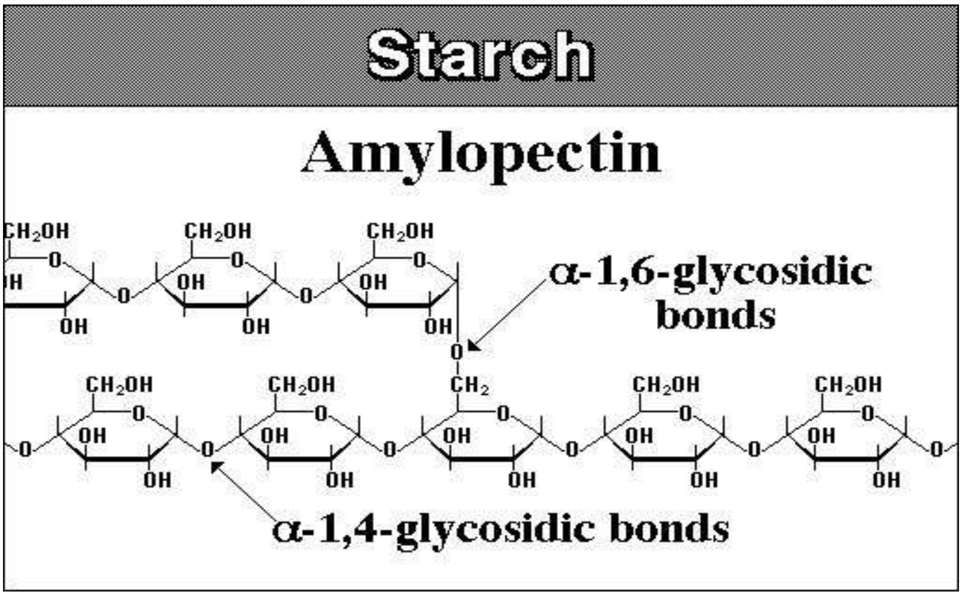

Figure 2.3 Structure of branched fraction amylopectin of rice starch.

(http://www.atue.edu/~nsw/ench485/lab5.htm)

2.3.1.3 Protein

Protein is the second most abundant constituent of brown rice, following and existing in the endosperm as bodies (aleurins). The aleurins are 1–4 μm in size and contain, in addition to 11.7% protein, 7.9% carbohydrates and globoids or phytate bodies, (9.4%) myo–inositol and 11.3% acid–soluble phosphorus. Protein content of the world rice collection has been surveyed and shown to vary from 5–17% with a mean of 10.5%, a significant correlation between total protein and lysine levels. Protein content of the rice caryopsis in brown rice is about 8% and that of milled rice is 7%. Protein is mainly distributed in the bran and pheriphery of the endosperm. The central part of the rice grain only contains a small proportion of rice protein. Rice protein has all essential amino acids, in rather a well–balanced proportion, for the human body. Though the amount of protein is not high, the quality of rice protein is one of the highest (Luh, 1980).

2.3.1.4 Lipids

Lipid content is 1.9% in brown rice and 0.5% in milled rice. Lipids on the surface of the rice caryopsis a composition of fatty acids and unsaponifiable matter closer to that of the rice hull than to bran and brown rice lipids. It is present in sperosomes (lipid droplets) of about 0.1–1 μm in size in the embryo and the aleurone layer. In the endosperm, the lipids are probably associated with protein bodies and starch granules in the membrane fraction as lipoprotein. In addition to membrane lipids, the starch granules contain bounds lipids (fat-by–hydrolysis), mainly as phospholipids and particularly, lysolecithin.

In general, lipids in brown rice are 80% of the bran and polish, and about one–third of this fraction is in the embryo. In degermed brown rice, about 70% of the total lipids are in the outer 8% fraction. Its outermost 1.4% milling fraction contains 40% fat, which constitutes about 40% of the total lipids of demerged brown rice. The fatty acid composition of brown rice and its fraction shows that oleic, linoleic, and palmic acids are the major constitutes. Bran lipids have higher contents of linoleic and linolenic acids, but lower contents of palmitic, palmitoleic, and stearic acids than milled–rice lipids. The phospholipid fraction varies from 3% to 12% of total milled–rice lipids. This fraction has a consistently higher content of palmitic acid than neutral fat in both brown and milled rice. Free fatty acids and mono-and diglicerides have the same three pricinpal acids, palmitic, oleic, and linoleic. Free fatty acids have higher linoleic and lower oleic acid contents than neutral fat, particularly in milled rice. The bran layers tend to have higher levels of all the acids than milled rice (Luh, 1980).

2.4 Rice grain quality

Grain quality of rice is determined by the factors such as grain appearance, nutritional value, cooking and eating quality. Spericity of rice is a term used to distinguish cultivars of rice that have unique properties like flavor, colour, nutrition and chemical composition. The physicochemical characteristics include grain length (L), grain breadth (B), L/B ratio, hulling and milling percentage. The cooking qualities are amylose content, water uptake, volume expansion ratio and grain elongation (Shilpa et.al , 2010).

2.4.1 Rice kernel form

2.4.1.1 Rough (paddy)

Rice that has been harvested from the plant with its hull (husk) intact is known as rough or paddy rice.

2.4.1.2 Brown (unmilled)

When the hull is removed from the rough, it is known as brown rice. However, not all rice with the hull removed is brown in color. The bran and germ that gives brown rice its color can vary from light yellow to red to dark purplish black. Rice bran and germ contains greater amounts of dietary fiber, vitamins, minerals and other health-related components than the center portion of the white rice kernel (endosperm). But those outer portions of the kernel also contain more lipid (fat) materials, making brown rice more susceptible to becoming rancid. It therefore has a shorter shelf life compared to milled white rice. Storage under cool conditions will lengthen its shelf life. Cooked brown rice is chewier in texture than its white rice counterpart and is described as having a slightly nutty flavor (rice quality categories, http://usda-ars-beaumont.tamu.edu/qual5.html).

2.4.1.3 White (milled) rice

Rice that has had its bran and hull layers removed by milling is called white, table, polished or milled rice. White rice cooks faster than brown rice and has a longer shelf life. Rice is traded as a white rice form in the world market. In the US, most white rice is fortified with iron, niacin, thiamin, and folic acid to enhance its nutritional quality (rice quality categories, http//usda-ars Beaumont.tamu.edu.qual15.html).

2.4.2 Grain shape

2.4.2.1 Long grain

The category known as long grain contains milled rice that is approximately three times longer than it is wide. Conventional U.S. long grain rice has 19 to 23% grain amylose content. After cooking, it is firm and fluffy (not sticky) (rice quality categories, http:usda-ars-beaumont.tamu.edu/qual5.html).

2.4.2.2 Medium grain

The medium grain rice category describes milled rice that is from 2.1 to 2.9 times longer than it is wide. Medium grain rice generally has an amylose content of 16–18% and after cooking, is soft, moist and sticky in texture. This type of rice is in general preferred by people from Japan, Northern China and North and South Korea (rice quality categories, http:usda-ars-beaumont.tamu.edu/qual5.html).

2.4.2.3 Short grain

Rice that is less than two times longer than it is wide is classified as short grain. In general, short grain rice has the cooking quality and amylose content similar to that of rice in the medium grain category. Because this type of rice is used for making sushi, some call it sushi rice.

2.5 Rice Quality

2.5.1 Physical property

2.5.1.1 Grain size and shape classification of milled rice

The size and shape of rice grain kernels were measured on the basis of standard classification of grain size, shape and weight of milled rice (Henry and Kettlewell, 1996).

Table 2.2. Standard classification of size and shape of milled rice.

Size classification		**Shape classification**	
Class	**Length (mm)**	**Class**	**Length/width**
Extra long	>7.0	Slender	>3.0
Long	6.0-7.0	Medium	2.4-3.0
Medium	5.0-5.99	Bold	2.0-2.39
Short	<5.0	Round	<2.0

Henery and Kettlewell (1996)

2.5.1.2 Grain appearance

Ten grains of milled rice without any defects were selected to measure grain appearance. The classification of grain appearance (endosperm opacity) was performed visually according to the following standard classification (Singh, et al., 2000) :

Table 2.3. Standard classification of grain appearance of milled rice.

Endosperm opacity	
White belly	On the dorsal side of the grain
White back	On the ventral side
White center	In the center

Henery and Kettlewell (1996)

2.5.1.3 Moisture content

Moisture content (MC) has a marked influence on all aspects of paddy and rice quality. It is essential that paddy be milled at the proper moisture content to obtain the highest head rice yield. Paddy is at its optimum milling potential at a moisture content of 14% wet weight basis. Grains with high moisture content are too soft to withstand hauling pressure which results in grain breakage.

2.5.1.4 Colour of grains

Colour is one of the most important cues by consumers to assess the quality of rice. It may be defined as the individual response to the visual signals generated by the light on a product. It is important to better understand and controlled of pigment changes in paddy, brown and milled rice. Colour stability is essential to attract a premium price of the rice quality and acceptance by the consumers to increase the market value.

The colour L* a*, b* and h^o values of paddy, brown and milled rice are important factors to determine the cooking quality and eating quality of rice. Factors important to the rice industry in assessing qualities of rice for domestic and export uses include hull, brown, milled rice and bran colour. Hull colour and anthocyanin pigmentation in the spiculus are factors that influence different areas of rice quality. Light hull colour of white or milled rice and bran (pericarp) colour affect quality in rice. Red rice is objectionable because red bran is not completety removed in regular milling, which detracts from the general appearance of conventional rice and results in reduced market values (Luh, 1980).

The colour of paddy, brown and milled rice as affected by water, insects and heat exposure can cause the grain to deteriorate through biochemical changes in the grain which may result in the development of off–odours and changes in the physical appearance.

Discolored milled rice grains, in many cases, are referred to as having a yellowing problem, which often makes the grains unattractive. Chemical and physical transformation, induced by heating and translocation of the colour from the rice husk and rice bran, cause the discoloration (Inprasit and Noonmhorm, 2001).

2.5.1.5 Determination to detect brown and milled rice

1) Head yield

In rice milling, the quality of the grain is often associated with the head rice yield (Bautista et al., 2000). Head rice refers to the whole grains of milled rice that can be obtained from a given quantity of clean paddy after complete milling. The broken rice particles larger than ¾ of the kernel are also considered as head rice. The yield is usually expressed as a weight percentage of paddy rice (Siebenmorgan et al., 1992). It can vary from as low as 25% to as high as 65% depending on the quality of the grain itself and the milling machine (IRRI , 2002d).

Head rice recoverability is an inherited trait, although environmental factors such as temperature and humidity during ripening are considered. The time of harvest and post harvest handling operations are known to influence grain breakage during milling. Head rice recovery is also dependent upon grain size, shape and appearance. In general, varieties with long bold grains and those having chalkiness give lower head rice yields. Varieties having medium long, slender and translucent grains give the best head rice yields.

Grain size and shape vary from one group of consumers to another. Some consumers prefer short, bold grains; others like the medium, long grains and others, long slender. Head rice yield is an important factor for grain market quality and is reflected in grain hardness.

Non–waxy rice is translucent. The opaque portion in the non–waxy grain contributes to low yield of head rice because of low grain hardness. The opacity of the endosperm is caused by loose packing of the starch and protein particles of the affected cells. Thus, the grain hardness may be related to the packing density of the starch and grain, as reflected in the gelatinization temperature and alkali spreading value. At different maturity levels, changes of alkali test values correlate with the hardness index (Jocelyn et al., 1991).

Since rice is consumed mostly in the form of whole grains and because of the greater economic value of the head rice, increasing the HRY in production is a universal goal (Sharma and Kunze, 1982). Reduction in the yield decreases the grain value since broken kernels are typically worth half the value of head rice (Webb et al., 1986, Muthukumarappan et al., 1992: Siebenmorgan et al., 1992: Siebenmorgan 1994: Cnossen and Siebenmorgan 2001; Zhang et al., 2003a and Cnossen et al., 2003).

Booker et al., 1992 and Abud–Archila et al., 2000 described the HRY to be especially sensitive to the mode of drying and is usually used in assessing the success or failure of the drying system. It is difficult to ascribe reduction in the yield to a single cause.

However, it is generally believed that the yield is strongly related to internal cracking or fissuring (Vellupilia and Pandey, 1990). Research has indicated that some breakage in the grains occurs because the kernels have previously been weakened by stress cracks (fissures) caused by rapid moisture absorption or desorption (Cnossen et al., 2003).

The effort of the rice breeders to develop new varieties, improve the design of shelling and milling equipment, and improve the drying conditions and treatments (parboiling, extractive milling) of the grain prior to or during milling have resulted in reducing fissuring and breakage. However, further means for minimizing the damage would benefit rice millers and farmers more.

A number of standardized testing methods have been developed and applied by different groups of researchers to determine the HRY. Depending on the methods and instruments used, the yield obtained from the same sample can be significantly different (Reid et al., 1998; Yadav and Jindal and Lioyd et al., 2001).

2) Imperfect grains

A. Broken grains in milled rice

Broken rice is generally based on the length of the rice particles. This is expressed as 1/8 unit of the length of the whole, unbroken milled rice grain. The whole, unbroken milled rice grain is defined as 8/8 =1. In some countries, the particle lengths in 1/10 of the units are used. However, we restrict ourselves to definitions based on 1/8 length units. Generally, we categorize milled rice as:

a. Head rice – a head rice grain has the particle length of 6/8 or more of the length of the whole, unbroken milled rice kernel.

b. Large broken grains–this is a milled rice grain with a particle length of the whole, unbroken milled rice kernel, but shorter than 6/8.

c. Small broken grains–small broken milled rice grains will not pass through a perforated sieve with round perforations of 1.4 mm, but the length of the grain is shorter than 3/8 of the whole, unbroken, milled rice kernel. In addition, small broken grains are greater in size than brewer's rice, but smaller than large broken grains. In some countries, a larger round perforation is used. The Philippines uses round perforations whose sizes are fixed at 1.59 mm (Jocelyn et al., 1991).

B. Chalkiness of grains

If part of the milled rice kernel is opaque rather than translucent, it is often characterized as "chalky" (IRRI, 2009). Chalkiness disappears upon cooking and has no effect on the taste or aroma; however, it downgrades milled rice. Excessive chalkiness is caused by interruption during the final stages of grain filling. Though chalkiness disappears upon cooking and has no direct effect on cooking and eating qualities, excessive chalkiness downgrades the quality and reduces milling recovery.

Chalkiness in rice is often referred to as "white belly", "white core" or "immature" depending on its location or within the endosperm. If part of the milled rice kernel is opaque rather than translucent, it is often characterized as "chalky". Chalkiness disappears upon cooking and has no effect on cooking and eating qualities; however, it lowers milling yields since chalky kernels tend to be weak and break more during milling. Excessive chalkiness is caused by interruption during the final stages of grain filling and being harvested at too high of a moisture level. Adverse weather conditions and cultural practices also influence the incidence of chalkiness (Blakeney, 1991).

Figure 2.4 Chalkiness of grains (***Source***: IRRI, 2005).

a. White belly rice (Otto, 2003)

This is a rice kernel with white, opaque areas on the belly or ventral side of the grain. The white area is a result of poorly developed starch granules in the peripheral layers of the endosperm. It is caused by insufficient transport of carbohydrates to the grain during ripening and is associated with large grain size varieties. Most frequently, grains at the top of the spikelet will change to white belly rice because of rapid grain filling and high temperature. White belly areas generally do not degrade the quality of the rice

b. White core rice (Otto, 2003)

This is a rice kernel with starch granules in the central cells of the endosperm that developed poorly. Although undesirable for table rice, this characteristic is often considered favorable for brewer's rice. It is determined by environment conditions during grain fill, around 15 days after heading. The conditions are amplified by over–fertilization with nitrogen.

c. Green rice (Otto, 2003)

Green rice is a result of harvesting and drying while the chloroplast still remains in the pericarp of the grain. White rice with small amounts of green kernels is sometimes preferred by consumers because it affords proof that the rice was not harvested too late and that it is a new crop. However, excessive counts of green immature kernels will increase the protein content resulting in low taste scores and a loss of market value.

d. Notched belly rice (Otto, 2003)

Notched belly rice kernels frequently have an hour glass appearance as a result of low temperatures during grain development because some cells ceased growing. The bran layer inside the notches remains intact during milling, thus lowering the grade. If the notches are deep, the kernel typically breaks during milling.

e. Rusty rice (burnt rice) (Otto, 2003)

Brown pigment staining of the pericarp is often a result of fungal infections of the kernel during periods of high humidity. The grain is usually misshapen. Milling does remove the off–color.

f. Milky–white rice (Otto, 2003)

This condition is when the rice is entirely opaque due to too poorly developed starch granules in the center of the endosperm. This occurs when the rice is subjected to low temperatures at the middle of the grain ripening stage. In general, this rice is slender with a non-uniform shape. It is treated with the screening instrument. This condition is the same as milky–white, except this rice does not have a surface luster. Most opaque rice kernels are caused by a temporary retardation in grain growth due to unfavorable conditions immediately after flowering.

g. Abortive rice (Otto, 2003)

This term refers to the remains of the ovary, which stops growing soon after fertilization

C. Cracked grains

Mechanical impact and overexposure to fluctuation and moisture conditions may lead to development of cracks in individual kernels. Cracks lead to easy infestation and development by mold and because of the breaks in the endosperm tissues. The nourishment that the embryo can get reduces the vitality of the seeds (Dong and Zhihuai, 2003).

The cracked kernels will break during cooking. Partial fissures as well as cracks across the entire kernel are considered and they are cumulative. In that, two partial fissures constitute one whole fissure for grading purposes. It is caused by the dehydration of dry rice kernels. Differential absorption of water by the endosperm leads to an uneven expansion of the cells. It can also be caused by too rapid drying under periods of high temperature.

Different combinations of cracked grains are described below:

a. Fissure across the entire kernel

b. Two fissures extending way across the kernel starting at the edge

c. One fissure attached to the edge, and another one at the kernel width

d. Two fissures across the width of the kernel, regardless of the start point

e. Intersecting fissures regardless of size

D. Discolored milled rice

Discolored milled rice grains are in many cases referred to as the yellowing problem, and often make the grains unattractive (Dillahuntyet et al., 2001). Chemical and physical transformations, induced by heating and translocations of color from rice husk and rice bran to the endosperm, cause the discoloration (Inprasit and Noonmhorm, 2001; Dillahunty at al., 2001). Delayed threshing causes yellowing of the grain in the field; it can be increased during drying and storage (Brook et al., 1992 and Brooker et al., 1992).

E. Defect grains

Before milling, paddy rice can be deteriorated through natural biochemical changes in the physical appearances that results in defect grains that are fully or partially darkened.

2.5.2 Chemical property

2.5.2.1 Amylose content

This characteristic of rice affects the cooked rice quality or influences the eating quality of rice. When the content is high, the amount of cooking water absorbed by the milled rice increases; the cooked rice will show high value expansion (not necessarily elongation) and a high degree of flakiness (easy to loosen or separate). The rice will also be dry, less tender and become hard upon cooling. When amylose is low, the cooked grains will be moist and sticky. Amylose determination used the empirical starch–ioding blue test to differentiate between long grain samples in which the amylose responsible for the development of the blue colour was leached from the ground rice at 77°C. The test may actually have been a measure of ruptured starch granules. The objective was overcome this by modification of the test using extraction at 99.5°C, but even this modified test is of limited value for determining amylose in milled rice in the 20–30% range. The original test has, however, been found to have a significant correlation of 0.860 with amylose content in the sample with a gelatinization temperature below 77°C and is used for detecting varieties with high gelatinization temperatures (Chapman and Hall, 1996).

Amylose has been identified as the major determinant for the cooking and eating quality of rice. Generally, the higher the amylose content of rice, the firmer the cooked grains of rice will be. Some types of rice are between 25 and 30% amylose. These high amylose levels tend to make the rice cook firm and dry. Rice with medium amylose content between 16 and 22% usually cooks softer and the grains stick together more readily. Waxy–rice has no amylose at all and is often referred to as sticky rice. Amylose content is important because firmness and stickiness are the two properties of cooked rice that influence consumer preference for, and the use of, difference classes of rice (Fitzerald et al., 2003).

The physical properties of starch are influenced by the amylose and amylopectin ratios. During gelatinization, the starch granules swell and form gel particles. In general, the swollen granules are enriched in amylopectin, while the linear amylose diffuses out of the swollen granules and makes up the continuous phase outside the granules. Waxy starches usually swell to a greater extent than their normal–amylose counterparts, and amylose is proposed to act as a resistant to swelling. Awazuhara, et al., 2000, described that the starch is degraded by the combined actions of enzymes, such as α–amylase, β-amylase and α-glucosidase, during cooking and processing.

Chapman and Hall (1996) reported that under the particular conditions used, the amylose responsible for the development of the blue occur was leached from ground rice at 77°C. The test may actually have been a measure of ruptured starch granules. These objections were overcome by modification of the test using extractions at 99.5°C but even this modified test is of limited value for determining amylose in milled rice in the 20–30% range. The original test has, however, been found to have a highly significant correlation of 0.860 with amylose content in samples with gelatinization temperatures below 77°C and is useful for detecting varieties with high gelatinization temperatures.

Amylograph studies are undertaken to simulate cooking and study changes occurring during pasting, cooking and cooling of aqueous starch systems. Amylose content correlated with pasting characteristics of rice has been measured by the amylograph.

The drop in viscosity after cooking for 20 minutes was also highly correlated with amylose content, indicating that resistance to disintegration of rice during cooking is also indicative of high amylose content. Set–back viscosity, which is the difference in viscosity on cooling to 50 °C and peak viscosity, is a measure of the retrogradation of amylose during cooling of the paste. This and the viscosity on cooling to 50°C have both been correlated to amylose content (Chapman and Hall, 1996).

According to Pomeranz (1987), rice must have an acceptable market, eating quality and good nutrition value. Grain quality is related mainly to the amylose/amylopectin ratio, which governs water absorption and volume expansion during cooking, as well as cohesiveness, color, gloss, and tenderness of cooked rice. Long grain types generally cook to dry, fluffy products that harden on keeping and are preferred by some. Short–grain rice tends to be more cohesive and moist and remains relatively tender when kept and consumed cold. Waxy (1–2% amylose) rice, in contrast to high amylose (over 25%) rice, is glossy and sticky when cooked. Rice with intermediate amylose contents and intermediate gelatinization temperatures are preferred in the tropics.

Amylose content is starch made up of about 90% of the dry matter content of milled rice. Starch is a polymer of glucose and amylase is a linear polymer of glucose. The amylose content of starches usually ranges from 15–35%. High amylose grains cook dry, are less tender, and become hard upon cooling. In contrast, low amylase rice cooks moist and sticky. Intermediate amylose rice is preferred in most rice growing areas of the world, except where low–amylose japonicas are grown. Based on amylase content, milled rice is classified in amylose groups as follows:

1) Waxy (1– 2% amylose)

2) Very low amylose content (2–9%)

3) Low amylose content (10–20%)

4) Intermediate amylose content (20–25% amylose) and

5) High amylose content (25–33% amylose) (IRRI and FAO, 2009)

2.5.2.2 Starch properties of rice

The amylose and amylopectin ratio determines many of the properties of cooked rice. Increasing amylose content improves the capacity of starch granules to absorb water and expand in volume without collapsing because of the greater capacity of amylose to hydrogen bond or retrograde. The texture of cooked rice and its gloss are principally determined by the amylose and amylopectin ratio of the starch. The amylose content and the structure of amylopectin of starch profoundly affect the final textural properties of cooked rice (Ong and Blanshard, 1995b).

Amylose is a type of starch found inside the microscopic granules which make up a single rice grain. Another starch-amylopectin forms the crystalline or ice–like "skeleton" of these granules. Scientists think that the amylose forms into long chain-like arrangements to fill up the space inside the granule. The ratio of amylose to amylopectin in starch, as indexed by amylose content, is the chief influence on eating quality. It correlates negatively with taste panel scores for cohesiveness, tenderness, and gloss of the boiled rice. The cooking and eating characteristics of rice are influenced by the amount of amylose found in the grains. This is because the starch granules in the grain expand during cooking, forcing out the chains of amylose in a process scientists call leaching. As the cooked rice cools, the leached amylose chains line up, lock together and form a gel.

2.5.2.3 Physicochemical characteristics of rice

1) Grain elongation

Linear elongation of kernels in cooking is one of the major characteristics of fine rice. In general, kernel elongation is measured as the lengthwise proportionate change. High volume expansion in cooking is still considered to be a good quality by working class people of Asia who do not care whether the expansion is lengthwise or crosswise. Commonly, urban people prefer the varieties that expand more in length than breadth. Lengthwise expansion without increase in girth is considered a highly desirable trait in some high quality rice (Sing et al., 2000). On the other hand, the cooking quality of rice is mainly determined by water uptake, volume expansion and kernel elongation (Sarathe et al.,1986). Kernel elongation is a physical phenomenon that is influenced by gelatinization temperature. Grain elongation of pre–soaked milled rice was associated with intermediate–amylose and low–gelatinization temperature (http://www.ricecrc.org/reader/tq_Amylose and amylopectin.htm).

2) Water absorption

Water absorption and volume expansion of the grains during cooking are directly affected by amylose content. Waxy rice, whose starch is all amylopectin, expands the least during cooking, and its cooked grains have a high bulk density. Cooked grain resistance to disintegration is also related to amylose content, with high amylose rice being the most resistant and waxy rice, the least resistant.

Cooked high–amylose rice is dry and fluffy and has a dull appearance and hard texture, but is whitest in color and has extreme volume expansion. However, water absorption of rice grains during cooking for the optimum texture is the same for all non–waxy rice, regardless of amylose content, and is mainly a function of the surface area of milled rice.

The second index is gelatinization temperature. Gelatinization temperature is directly related to cooking time. Samples with a higher gelatinization temperature require a longer cooking time than those with a low gelatinization temperature. The gelatinization temperature ranges from 55 to 79°C. Rice cultivars can be classified as low (55–69.5°C), intermediate (70–74°C) and high (>74°C).

For both waxy and non–waxy rice, differences in gelatinization temperature are related to the physical properties of raw starch but not those of cooked rice. The micellar structure of the molecules in the granules seems to be the main factor involved in varietal differences in gelatinization temperature. This structure is reflected by the case of corrosion with acid by the density of the starch granules (Jocelyn et al., 1991).

The water absorption values of the hydrated grains agreed with the cohesive properties and cooking characteristics of the grain. Higher water absorption values obtained under these conditions indicated poor cooking quality and stickiness. Long grains yielding dry fluffy cooked products were characterized by low water absorptions at 70°C. However, it was found that high amylose rice generally absorbs more water and expands more during cooking at 99°C in excess water than low amylose rice. Differences in the above findings are probably due to the different cooking temperatures employed through the gelatinization temperature.

2.6 Factors affecting cooking quality

2.6.1 Variety

2.6.1.1 Physical characteristics of rice

Grain size and shape affecting the cooking and eating quality such as grain dimension:

1) Long grain rice

Long grain rice has a long, slender kernel, four to five times longer than its width. Cooked grains are separate, light and fluffy.

2) Medium grain rice

Medium grain rice has a shorter, wider kernel (two to three times longer than its width) than long grain rice. Cooked grains are more moist and tender, and have a graeter tendency to cling together than long grain.

3) Short grain rice

Short grain rice has a short, plump, almost round kernel. Cooked grains are soft and cling together.

2.7 Drying methods

The purpose of drying is to reduce the moisture content of rough rice to a level safe for storage. As even short term storage of high moisture paddy rice leads to quality deterioration, it is important to dry rice grains as soon as possible after harvesting, ideally within 12 hours.

Table 2.4 Moisture content for storage of paddy and potential problems when the moisture content exceeds these limits.

Storage period	Required MC for safe storage	Potential problems
2 to 3 weeks	14-18%	Molds, discoloration, respiration loss
8-12 months	13% or less	Insect damage
More than 1 year	9% or less	Loss of viability

(**Source**: IRRI, 2004)

Drying is one of the most important technologies for the preservation of grains. Grain must be dried to the levels of moisture suitable for storage without spoilage; the levels depend on the specific grains. Sun drying has been practiced extensively since ancient times. However, the technique is not suited for large quantities of various grains that today must be dried commercially. Drying is a complex operation involving the transient transfer of heat and mass along with several rate processes, such as physical or chemical transformations that, in turn, may cause changes in product quality as well as mechanisms of heat and mass transfer. Physical changes that may occur include shrinkage, puffing, crystallization and glass transitions. In some cases, desirable and undesirable or biochemical reactions may occur leading to changes in color, texture, odor, or properties of the solid product.

2.7.1 Sun drying method

Sun drying is the traditional method for drying and is still preferred in Asia because of its low cost compared to mechanical drying. It requires little investment and is CO_2 neutral since it uses the sun as a heat source.

Sun drying has some limitations: 1. The weather cannot be controlled during drying. 2. Any delay leads to excess respiration and fungal growth causing losses and yellowing. 3. It is labor intensive and has limited capacity 4. Temperature control is difficult. Over-heating or re-wetting of grains can result in low milling quality as a result of cracks developing in the kernels (IRRI, 2004).

Sun drying has many problems but many farmers in Asian countries use traditional methods like sun drying. This method affects rice quality, influences damage, and is subject to insect damage when the rice is late for storage. Sun drying is also advantageous because it is easy, dries quickly on mats or canvases in their home and is economically cheapest because most farmers cannot invest in a commercial drying system.

Sun drying is a traditional method for reducing the moisture content (MC) of paddy by spreading the grains in the sun. The sun heats up the grains and also the surrounding air. This causes the water to evaporate from the grains. Sun drying is a traditional method for drying and is still preferred in Asia because it is cheap compared to mechanical drying since it uses the sun as a heat source and is friendly to the environment. The limitations of sun drying include the following: it is not possible during rain and at night, any delay leads to excess respiration and fungal growth causing losses and yellowing, it is labour intensive and has limited capacity, and temperature control is difficult. Overheating or re-wetting of grains can result in low milling quality as a result of cracks developing in the kernels (IRRI, 2004).

2.7.1.1 Factors affecting sun drying

1) Temperature and humidity of ambient air. The rate at which rice dries is affected significantly by the temperature and humidity of the air that moves over or through the grains. For this reason, in most tropical, humid climates, sun drying is only successful during the first few hours in the middle of the day.

2) Initial moisture content of grains: wet grains dry at a higher drying rate than comparatively dry grains.

3) Often public roads are used for sun drying. This pollutes the grain, hinders traffic and can cause accidents and therefore, in different counties, efforts are underway to abolish drying on public roads.

4) Air velocity natural convection is usually not enough to transport large amounts of evaporated moisture away from the grain. Therefore, drying rates are higher on windy days compared to days without wind.

General guidelines for proper sun drying:

a. Prevent contamination of grains with other materials and keep animals off the grains.

b. Monitor grain moisture content and grain temperature.

2.7.2 Artificial drying

2.7.2.1 Batch dryers

The main components of the system are a bin with perforated floor, a grain spreader, a fan and heater unit, a sweep auger and underfloor unloading auger. The heater fan starts when the first load of grain is put in and continues to operate as long as is required to lower the average grain moisture contetnt to the desired level. The drying rate depends on several variables, such as drying time, grain depth, temperature of the heated air, and airflow rate. The final depth is selected by noting the pressure drop in a manometer. Airflow is determined from the charts supplied with the fan unit. Usually a rate of 450 m^3/h per m^3 of grain is recommended for efficient drying. For a given grain depth, raising the air temperature speeds up the drying, but increases the chance of overdrying near the floor.

2.7.2.2 Recirculating dryers

In a recirculating type of dryer, grain is constantly mixed while drying. A slanted floor causes the grain to move towards the centre of the dryer. The auger picks up the grain and delivers it to top of the grain bin. The result is a more uniformly dried crop than that obtained using non–recirculating types.

2.7.2.3 Continuous flow dryers

Continuous flow dryers are elevator grain dryers characterized by high capacity, and high temperature that fall into four categories: crossflow, concurrent, counterflow and mixed. Crossflow models dry grain non–uniformly, causing considerable stress cracking of the grain kernels. In a concurrent flow bed, air and grains enter at the same point and move in the same direction to the exit, though as in all types of dryers, the air traverse time is a few seconds, whereas the grain may spend minutes or hours in the bed. Because of this, air temperature falls quickly and grain does not reach the inlet temperature and can therefore be higher than for the crossflow or counterflow types without significant grain damage occurring. Mixed–flow dryers dry the grain more uniformly: the dried grain is usually of higher quality than that dried in crossflow models. Conccurentflows have counterflow coolers and produce the highest grain quality. Their disadvantages is the relatively high capital cost and the complexity of the technology.

2.7.2.4 Portable dryer

Portable dryers are units that are either used by a farmer who has grain bins scattered in various locations or those who use custom drying at the farm. There are two types: non-recirculating and recirculating dryers (Srzednicki, 1997).

2.7.3 Hot air oven dryer or oven drying

Oven drying is one of the methods to dry paddy and determines the influence on drying characteristics and the resultant milling quality of storing high moisture content (MC) of rough rice. After harvest, drying at 60°C and a moisture content of 14% achieves high head rice yield and milling quality (Siebenmorgen, 2005). In general, mechanically dried grains will produce better quality rice compared to sun drying. Mechanical drying will lead to more uniform drying of grains and higher milling yield and head rice recovery. Since rice quality is becoming more important to rice consumers, medium–sized grain dryers have become a common sight throughout Asia. For the production of premium quality rice, mechanical drying with heated air dryers is highly recommended. The circulation allows for the uniformity of dried grains. Automatic drying air temperature control will minimize the drying rate, and at the same time, reduce over heating or over drying (IRRI, 2004). Cnosesen and Siebenmorgen (2000), described that the drying temperature of 60°C and tempering period at 45°C resulted in a decrease of 25% in the percentage of fissured kernels that can be managed in respect to tempering at a low temperature. Cnosesen et al. (2003) reported the tempering temperature of 60°C can increase HRY and reduce the number of fissured kernels.

Chen et al. (1997) reported that variety, temperature and relative humidity are the main factors that lead to HRY decrease. Some changes in rice functionally associated with the temperature and time used in drying have been reported. Mullenet et al. (1998) observed that a high temperature (54.3°C) resulted in softer cooked rice kernels, but higher cohesiveness based on the texture profile analysis with a texture analyzer. Champagne et al. (1997) concluded that the rice flavor density at 15% moisture content is better than the 12% moisture content, and that the rice whiteness on flavor density is relevant to moisture content and variety. Wiset et al. (2001) noted that head rice yield, amylose content, gel consistency, water absorption, and volume expansion were affected by the method or temperature used in drying rough rice.The influences of drying temperature on rice taste quality were studied.

Artificial drying provides a means of reducing grain moisture content so that grains can be stored safely, so that there will be no price dockage because of high moisture content when the grain is sold. Low storage moisture content also reduces the potential for insect and mold damage. By having a grain drying system, a farmer can harvest grain much earlier, thus giving more individual control over the grain harvesting operation and providing many drying options.

2.7.4 Quality changes of rice after drying

2.7.4.1 Physical properties of paddy

Simulation of heat and moisture transfer phenomena during drying and storage of the grain requires physical, thermal and moisture–transport properties of the grains. Many physical characteristics have been described and used for rice grains, including kernel weight, sphericity, roundness, size, volume, shape, surface area, bulk density, and kernel density. These properties vary widely, depending on the MC, temperature and density of cereal grains (Sablani and Ramaswamy, 2003). According IRRI (2002c), there are six main physical characteristics used to determine the quality of paddy rice: moisture content, maturity, varietal purity, dockage, discolored grains and cracked grains.

1) Moisture content

Moisture content (MC) has a marked influence on all aspects of paddy and rice quality. It is essential that paddy be milled at the proper moisture content to obtain the highest head rice yield. Paddy is at its optimum milling potential at a moisture content of 14% wet weight basis. Grains with a high moisture content are too soft to withstand hauling pressure which results in grain breakage.

2) Colour

Factors important for the rice industry in assessing qualities of rice for domestic and export uses include hull, brown, milled rice and bran colour. Hull colour and anthocyanin pigmentation in the spiculus are factors influencing different areas of rice quality. Light hull colour of white or milled rice and bran (pericarp) colour affect quality in rice. Red rice is objectionable because red bran is not completety removed in regular milling, which detracts from the general appearance of conventional rice and results in reduced market values (Luh, 1980).

2.7.4.2 Physical property of brown rice

1) Colour

The colour L* a*, b* and h^o values are factors that are important for the rice industry in assessing qualities of rice for domestic and export use including hull, brown, milled rice and bran colour. Hull colour and anthocyanin pigmentation in the spiculus are factors influencing different areas of rice quality. Light hull colour of white or milled rice bran (pericarp) colour affect quality in rice. Red rice is objectionable because red bran is not completety removed in regular milling, which detracts from the general appearance of conventional rice and results in reduced market values (Luh, 1980).

2) Head yield

Head rice refers to the whole grains of brown rice that can be obtained from a given quantity of clean paddy after complete milling. The yield is usually expressed as a weight percentage of paddy rice (Siebenmorgen et al., 1992). It can vary from as low as 25% to as high as 65% depending on the quality of the grains and the milling machine (IRRI, 2002d). Defect grains are sometimes attacked by insects during crop production and depend on weather conditions during harvesting, threshing and drying.

2.7.4.3 Physical properties of milled rice

1) Colour

The color L* a*, b* and h^o values factor are important rice industry in assessing qualities of rice for domestic and export uses including hull, brown, milled rice and bran colour. Hull colour and anthocyanin pigmentation in the spiculus are factors influencing different areas of rice quality. Light hull colour of white or milled rice and bran (pericarp) colour affect quality in rice. Red rice is objectionable because red bran is not completety removed in regular milling, which detracts from the general appearance of conventional rice and results in reduced market values (Luh, 1980).

2) Head yield

The head rice yield depends not only on variety and crop management, but also on the management of postharvest operations and of the drying conditions used to dry the rice in particular (Brooker et al., 1992). The yield is especially sensitive to the mode of drying and is usually used to asses the success or failure of the rice drying system (Siebenmorgen, 1994).

2.7.4.4 Cooking quality

1) Elongation ratio

Linear elongation of kernels in cooking is one of the major characteristics of fine rice. In general, kernel elongation is measured as the lengthwise proportionate change. High volume expansion in cooking is still considered to be a good quality by the working class people of Asia who do not care whether the expansion is lengthwise or crosswise. Commonly, urban people prefer the varieties that expand more in length than breadth. Lengthwise expansion without increase in girth is considered a highly desirable trait in some high quality rice (Sing et al., 2000). On the other hand, the cooking quality of rice is mainly determined by water uptake, volume expansion and kernel elongation (Sarathe et al., 1986). Kernel elongation is a physical phenomenon that is influenced by gelatinization temperature. Grain elongation of pre-soaked milled rice is associated with intermediate-amylose and low-gelatinization temperature (http://www.ricecrc.org/reader/tq_Amylose and amylopectin.htm).

2) Water absorption

Water absorption and volume expansion of the grains during cooking are directly affected by amylose content. Waxy rice, whose starch is all amylopectin, expands the least during cooking, and its cooked grain has a high bulk density. Cooked grain resistance to disintegration is also related to amylose content, with high amylose rice being the most resistant and waxy rice, the least resistant.

Cooked high–amylose rice is dry and fluffy and has a dull appearance and hard texture, but is whitest in color and has extreme volume expansion. However, water absorption of rice grains during cooking for the optimum texture is the same for all non–waxy rice, regardless of amylose content, and is mainly a function of the surface area of milled rice.

The second index is gelatinization temperature. Gelatinization temperature is directly related to cooking time. Samples with a higher gelatinization temperature require a longer cooking time than those with a low gelatinization temperature. The gelatinization temperature ranges from 55 to 79°C. Rice cultivars can be classified as low (55–69.5°C), intermediate (70–74 °C) and high (>74°C).

For both waxy and non–waxy rice, differences in gelatinization temperatures are related to the physical properties of raw starch, but not those of cooked rice. The micellar structure of the molecules in the granules seems to be the main factor involved in varietal differences in gelatinization temperature. This structure is reflected by the case of corrosion with acid by the density of the starch granules (Jocelyn et al., 1991).

3) Hardness of cooked rice

Eating quality is determined mainly by the texture of cooked rice (tenderness or hardness and cohesiveness or stickiness) measured by instruments. Amylose has a major influence on the eating quality. The same relationship of tenderness or cohesiveness to amylose is obtained regardless of whether the cooking is done at the same rice-water ratio or at an optimum rice–water ratio.

4) Stickiness of cooked rice

Stickiness of cooked rice correlatesd negatively with amylose content, whereas the hardness of cooked rice shows a positive correlation with amylose content. However, hardness and stickiness of cooked rice are significantly negatively correlated with each other. This shows that varietal differences in the texture of cooked rice of similar intermediate amylose contents are associated with differences in the hardness of cooked rice rather than with stickiness differences. Among intermediate amylose rice, soft cooked rice is associated with soft gel consistency and low amylograph consistency of the final gelatinization temperature (Jocelyn et al., 1991).

2.8 Storage conditions and time on rice quality

2.8.1 Grain conditions

The grain conditions refer to its quality. An increase in the amount of cracked, damage kernels in stored grain can increase spoilage and thereby reduce grain quality. This is one of the reasons that it is impossible to establish an absolute maximum safe storage moisture content for grain. Grain in poor conditions must be dried to a lower moisture content than grain in good conditions if it is to be stored safely over long periods.

2.8.2 Storage time

The length of the storage period influences the amount of spoilage in grains. Microbial growth would be difficult to detect. Over long storage periods, this effect accumulates and can eventually be detected. In general, the longer the storage period, the lower the moisture content should be to ensure safe storage.

2.8.3 High moisture content of storage

High moisture grain (above 23%) can be stored under conditions where oxygen is excluded from the stored mass. If high moisture grain is placed in a hermitically sealed space, the aerobic microorganisms present in the grain will use the existing oxygen. Bacteria are grown under oxygen–free conditions.

To store the grain successfully, grain and the atmosphere in which it is stored must be maintained under conditions that discourage or prevent the growth of microorganisms that cause spoilage. The grain must have a MC of less than 13–14% and be protected from insects, rodents and from absorbing moisture from the atmosphere or rain. If the grain is purposed for seeds, the moisture should be reduced to 12% before storage (IRRI, 2002b).

2.8.4 Quality changes of rice during storage

2.8.4.1 Physical properties of paddy

1) Moisture content

Moisture content (MC) has a marked influence on all aspects of paddy and rice quality. It is essential that paddy be milled at the proper moisture content to obtain the highest head rice yield. Paddy is at its optimum milling potential at a moisture content of 14% wet weight basis. Grains with a high moisture content are too soft to withstand hauling pressure which results in grain breakage.

2) Colour

Colour is one of the most important cues by consumers to assess the quality of rice grains. It may be defined as the individual response to the visual signals generated by the light on a product. It is important to better understand and control pigment changes in paddy, brown and milled rice, and colour stability is essential to attract a premium price of rice quality.

2.8.4.2 Physical properties of brown rice

1) Colour

The colour L* a*, b* and h^o values are important factors for the rice industry in assessing qualities of rice for domestic and export uses including hull, brown, milled rice and bran colour. Hull colour and anthocyanin pigmentation in the spiculus are factors influencing different area of rice quality. hull colour of white or milled rice, and bran (pericarp) colour affect quality in rice. Red rice is objectionable because red bran is not completety removed in regular milling, which detracts from the general appearance of conventional rice and results in reduced market values (Luh, 1980).

The colour of brown rice increased because the pigments of rice increased during storage. The increase in yellow pigments of brown rice indicated that the bran and outer endosperm containing yellow pigment of stored rice at 37°C increased more than at 25°C. To gain more insight into the different rice pigments, identification of the rice pigments present in the different storage time is needed.The b* value that come from brown pigments increased during storage, brown pigments provide an index for evaluating the intensity of the browing reaction that was caused maillard reaction (Jirasak, 2008).

2) Head yield

When the hull is removed from rough rice, it is called brown rice. However, not all dehulled rice is brown in color. The outer bran layer of the grain and embryo (germ) is what gives rice its color and it varies from light yellow to red dark purplish black. Rice bran and germ contain greater amounts of dietary fiber, vitamins, minerals and other health-related components than the white center portion of the kernel (endosperm). But, those outer portions of the kernel also contain more lipid (fats) material, making brown rice more susceptible to becoming rancid (spoiling). Brown rice, therefore, has a shorter shelf life compared to milled white rice. Storage under cool conditions will lengthen its shelf life. Cooked brown rice has higher fiber content and is chewier in texture than its white rice counterpart and is described as having a slightly nutty flavor (Rice grain quality, USDA-ARS-rice research unit quality program).

2.8.4.3 Physical properties of milled rice quality

1) Colour

The color L* a*, b* and h^{o} values are important factors for the rice industry in assessing qualities of rice for domestic and export uses including hull, brown, milled rice and bran colour. Hull colour and anthocyanin pigmentation in the spiculus are factors influencing different areas of rice quality. Light hull colour white or milled rice bran (pericarp) colour affect quality in rice. Red rice is objectionable because red bran is not completety removed in regular milling, which detracts from the general appearance of conventional rice and results in reduced market values (Luh, 1980).

2) Head yield)

One of the most important aspects of rice grain quality is its miling yield. During the process of miling, the hull is removed from rough rice using a huller to yield brown rice. After the hull is removed, the embryo and the bran layer is removed from the brown rice through an abrasive mill to reduce total rice (broken and whole kernels). The step is separation of the whole (intact) kernels from the broken grains, using screens sizes for long, medium or short grain varieties to produce whole grain rice. Head rice milling yield is the percentage of whole kernels recovered after milling and removal of the broken kernels. Producers are paid less for broken kernels than for whole.

2.8.4.4 Chemical properties

Storage induced changes in the pshycochemical properties of rice may be both desirable and undesirable depending on storage conditions, variety, and end user requirements. Moisture content, storage temperature and storage time are the factors most influential on the chemical, physical and functional qualities of rice during post harvest storage. The nature of the change is primarly temperature dependent. Quality shifts generally occur faster with increasing temperature and moisture content. Conversely, under experimental conditions, favorable rice quality has been preserved for years at sub–zero temperatures. In the United States, storage temperatures, moisture content, and storage time varies between 50 and 95^{o}F, 10 and 15% and 24 months, respectively.

Rice quality shifts begin during field drying and continue after harvest. Changes in rice quality as a result of aging are due in large part to enzymatic reactions involving protein, starch and lipid. Generally, the outer layers are more susceptible to these reactions than the endosperm of the rice kernel. Although the phsyicochemical properties of brown rice may exhibit greater changes, milled characteristics can also be altered during storage (rice quality workshop, 2003).

1) Protein

Protein content affects texture, tenderness, and cohesiveness of cooked rice. Proteins are most concentrated in the outer layers of the rice kernel, but significant amounts are also present in the endosperm. Total protein does not change considerably during storage; however, the chemical properties of the proteins can be altered substantially. 80 to 90% of the storage protein in rice is oryzenin (glutelin). After one year of the storage at 104^{o}F (40 ^{o}C), the molecular weight of oryzenin doubled in both medium and long grain varieties. Small changes in the ratio of oryzenin to other proteins were also observed especially where a marked decrease in free amino acid content was apparent. Free amino acid related to non–enzymatic color changes in stored rice and were influenced by temperature and moisture content.

One mechanism by which protein influences texture is hypothesized to involve the regulation of water diffusion into the starch granule and which consequently alters the water and time requirements for cooking. Secondly, protein may impede starch gelatinization. It has been suggested that starch associated proteins confer strength to the gelatinized granule by reducing the leaching of amylose molecules or by physically holding the starch granule together. Thus, during storage the interaction of protein with starch diminishes, thereby altering texture due to changes in water diffusion properties and gelatinization processes during cooking. The brewing industry is reluctant to use rice stored for long periods because it requires higher temperatures for gelatinization and converts slowly to fermentable sugars.

Rice textural properties change significantly in the months following harvest. Many of the functional changes that occur during storage that influence cooking properties, such as cooking time, water uptake, and stickiness, are caused by protein–starch interactions. The aging process, especially at high storage temperatures, results in fewer interactions between oryzenin and starch and/orits components (e.g., amylose). Cooking time increased and after cooking, stickiness decreased during storage of both brown and milled rice, especially at high temperarures (rice quality workshop, 2003).

2) Carbohydrates

The rice kernel is more than 90% crboohydrates. Reducing sugars (e.g., maltose) increase and non-reducing sugars (e.g., sucrose) decrease during storage when subjected to temperatures of 77^{o}F (25^{o}C) or greate. In contrast, degradation of carbohydrates to CO_2 is generally very small, but can become significant at moisture contents greater than 14% and high temperatures. Similarly, total starch content does not change appreciably during storage, although small changes in starch properties have been observed. Changes in the molecular weight of starch and its component (amylose and amylopectin) may be significant albeit small. Enzymes, such as anylases, initiate starch synthesis and degradation processes in the rice grain during storage. Major changes in hardness, gel consistency, and viscosity values require approximetly three months. Therefore, textural evaluation should be done on samples aged at least three months.

The greatest textural changes would be expected in high amylose varieties. Cold storage preserves cohesiveness, a desired trait in Japan (rice quality workshop, 2003).

3) Lipids

Most of the lipids in rice grains are concentrated in the outer layers. The endosperm contains a fraction of the total lipid content. Lipolytic enzymes (or lipases) catalyze the hydrolysis of kernel lipids (oil). The enzymes are both endogenous and of microbial origin. Lipases and lipids are compartmentalized in the testa layer and the aleurone and germ, respectively. Therefore, these reactions occur principally in the outer layer of the rice where lipids are concentrated. Dehulling rice disrupts these outer layers, lipids diffuse and make contact with the lipases and hydrolysis of lipids to fatty acids begins. Microbial produced lipases located on the kernel surface also come in contact with kernel lipids.

The rate of free fatty acid formation in brown rice depends on the degree of surface disruption, moisture content, microbial levels, and temperature of the grain mass. Approximately 30% of the kernel oil content can be converted to fatty acids within a week under high humidity and temperature. The lipids hydrolyze or oxidize to fatty acids or peroxides during aging. High temperature accelerates lipid oxidation. Fatty acids are in turn oxidized to an array of secondary metabolic compounds. This causes increased acidity and a deterioration of taste and the production of rancid odors. It is the oxidation of fatty acids that contributes to off–odors and taste associated with ‘spoiled’ rice. The deterioration of brown rice during storage is very fast because of the large amounts of lipid and lipolytic enzymes present in the bran (rice quality workshop, 2003).

4) Odor and flavor

The odor and flavor of cooked rice changed with time even when stored in airtight conditions. Aldehydes and ketones were idenfied as the dominant source of the off flavors, although other undesirable compounds were also detected (e.g., sulfur, dioxide, hydrogen sulfide). Most of the detected volatile compounds were products of lipids, amino acids and/or vitamin decomposition. Well polished rice (12%) retained its flavor for a longer period than did polished rice. This was expected because the outer layers of the kernel contain the highest levels of oxidizable compounds that contribute to off flavor (rice quality workshop, 2003).

2.8.5 Cooking quality

1) Elongation ratio

Linear elongation of kernels in cooking is one of the major characteristics of fine rice. In general, kernel elongation is measured as the lengthwise proportionate change. High volume expansion in cooking is still considered to be a good quality by the working class people of Asia, who do not care whether the expansion is lengthwise or crosswise. Commonly, urban people prefer the varieties that expand more in length than breadth. Lengthwise expansion without increase in girth is considered a highly desirable trait in some high quality rice (Sing, et al., 2000). On the other hand, the cooking quality of rice is mainly determined by water uptake, volume expansion and kernel elongation (Sarathe et al., 1986). Kernel elongation is a physical phenomenon that is influenced by gelatinization temperature. Grain elongation of pre-soaked milled rice is associated with intermediate-amylose and low–gelatinization temperature (http://www.ricecrc.org/reader/tq_Amylose and amylopectin.htm).

2) Water absorption

Water absorption and volume expansion of the grains during cooking are directly affected by amylose content. Waxy rice, whose starch is all amylopectin, expands the least during cooking, and its cooked grain has a high bulk density. Cooked grain resistance to disintegration is also related to amylose content, with high amylose rice being the most resistant and waxy rice the least resistant.

Cooked high-amylose rice is dry and fluffy and has a dull appearance and hard texture, but is whitest in color and has extreme volume expansion. However, water absorption of rice grains during cooking for the optimum texture is the same for all non–waxy rice, regardless of amylose content, and is mainly a function of the surface area of milled rice.

The second index is gelatinization temperature. Gelatinization temperature is directly related to cooking time. Samples with a higher gelatinization temperature require a longer cooking time than those with a low gelatinization temperature. The gelatinization temperature ranges from 55 to 79°C. Rice cultivars can be classified as low (55–69.5°C), intermediate (70–74°C) and high (>74°C).

For both waxy and non–waxy rice, differences in gelatinization temperature are related to the physical properties of raw starch, but not those of cooked rice. The micellar structure of he molecules in the granules seems to be the main factor involved in varietal differences in gelatinization temperature. This structure is reflected by the case of corrosion with acid by the density of the starch granules (Jocelyn et al., 1991).

3) Hardness of cooked rice

Eating quality is determined mainly by the texture of cooked rice (tenderness or hardness and cohesiveness or stickiness) measured by instruments. Amylose has a major influence on the eating quality. The same relationship of tenderness or cohesiveness to amylose is obtained regardless of whether the cooking is done at the same rice–water ratio or at an optimum rice–water ratio.

4) Stickiness of cooked rice

Stickiness of cooked rice correlates negatively with amylose content, whereas the hardness of cooked rice shows a positive correlation with amylose content. However, hardness and stickiness of cooked rice are significantly negatively correlated with each other. This shows that varietal differences in the texture of cooked rice of similar intermediate amylose contents are associated with differences in the hardness of cooked rice rather than with stickiness differences. Among intermediate amylose rice, soft cooked rice is associated with soft gel consistency and low amylograph consistency of the final gelatinization temperature (Jocelyn et al., 1991).

2.8.6 Factors affecting quality during storage

Storage is one of the most sensitive postharvest particles. Infestation by rats, insects and other pests is common. High initial moisture content will result in a higher percentage of yellow grains, spoiled grains and mold. Storage problems that occur are the result of unsuitable moisture and temperature regimes often favoring mold and/or insect activities. Postharvest yellowing of rice is a major problem in the humid tropics (Philips et al., 1988).

Non–uniformity or variation in MC has been described to be a problem for storage as it shortens permissible storage duration for rice grains. The pretense of some grain kernels with an MC above the average level of the MC can reduce the storage life of the entire lot of grains (Tater, 1987). Other factors are as follows:

2.8.6.1 Cultivars

Many countries produce a variety of rice grains, including:

1) Long: Long slender kernels which produce light, fluffy rice.

2) Medium: Short, wide kernels which are moist and tender when cooked.

3) Short: Short, round kernels which are soft and cling together when boiled. (Rice Grain www.MonsterMarketplace.com).

2.8.6.2 Grain history

There are many unproven mythological tales as to how rice came to be, though historians hold little or no stock in any. Most believe the roots of rice come from 3000 BC India, where natives discovered the plant growing in the wild and began to experiment with it. Cultivation and cooking methods are thought to have spread to the west rapidly and by medieval times, southern Europe saw the introduction of rice as a hearty grain.

The first cultivators of rice in America did so by accident after a storm damaged a ship docked in the Charleston, South Carolina harbor. The captain of the ship handed over a small bag of rice to a local planter as a gift, and by 1726, Charleston was exporting more than 4,000 tonnes of rice a year.

Today, rice is grown and harvested on every continent except Antarctica, where conditions make its growth impossible. The majority of all rice produced comes from India, China, Japan, Indonesia, Thailand, Burma, and Bangladesh. Asian farmers still account for 92% of the world's total rice production. More than 550 million tonness of rice are produced annually around the globe. In the United States, farmers have been successfully harvesting rice for more than 300 years.There are thousands of strains of rice today, including those grown in the wild and those which are cultivated as a crop.

2.8.6.3 Maturity

Immature rice kernels are very slender and chalky and result in the production of excessive bran, broken grains, and brewers' rice.

2.8.6.4 Grain processing

Rice cultivation is well–suited to countries and regions with low labor costs and high rainfall, as it is labor-intensive to cultivate and requires ample water. Rice can be grown practically anywhere, even on a steep hill or mountain. Although its parent species are native to Asia and certain parts of Africa, centuries of trade and exportation have made it commonplace in many cultures worldwide.

The traditional method for cultivating rice is flooding the fields while, or after, setting the young seedlings. This simple method requires sound planning and servicing of the water damming and channeling, but reduces the growth of less robust weed and pest plants that have no submerged growth state, and deters vermin. While flooding is not mandatory for the cultivation of rice, all other methods of irrigation require higher efforts in weed and pest control during growth periods and a different approach for fertilizing the soil.

2.8.6.5 Drying method

1) Sun drying

Sun drying is the traditional method for drying and is still preferred in Asia because of its low cost compared to mechanical drying. It requires little investment and is CO_2 neutral since it uses the sun as a heat source.

Sun drying has some limitations: 1. The weather can not be controlled during drying 2. Any delay leads to excess respiration and fungal growth causing losses and yellowing 3. It is labor intensive and has limited capacity 4. Temperature control is difficult. Over–

heating or re-wetting of grains can result in low milling quality as a result of cracks developing in the kernels (IRRI, 2004).

2) Hot air oven dryer

Oven drying is one of the methods to dry paddy and determines the influence on drying characteristics and the resultant milling quality of storing high moisture content (MC) of rough rice. After harvest, drying at 60°C and a moisture content of 14% achieves high head rice yield and milling quality (Siebenmorgen, 2005). In general, mechanically dried grains will produce better quality rice compared to sun drying. Mechanical drying will lead to more uniform drying of grains and a higher milling yield and head rice recovery. Since rice quality is becoming more important to rice consumers, medium–sized grain dryers have become a common sight throughout Asia. For production of premium quality rice, mechanical drying with heated air dryers is highly recommended. The circulation allows for the uniformity of dried grains. Automatic drying air temperature controls will minimize the drying rate, and at the same time, reduce over heating or over drying (IRRI, 2004).

3) Cleaning of the grains

The objective of the mechanical cleaning system, one of the steps in the milling process, is the different removal of any foreign material or objectionable seeds that may be present in the incoming paddy. Foreign materials include straw, dust, stones, metal, glasss and animal life. Objectionable seeds include any agricultural seeds other than rice. Mechanical cleaning is a logical process containing several steps, and each step is depedent on the efficiency of the preceeding steps. This process is accomplished by using differences in the physical properties of rice and anything other than ric to remove objectionable materials.

Paddy cleaners provide screening and aspiration operations. A slotted perforated screen (upper screen) remove objects that are appreciably wider than rice (i.e., seeds in pods, corn, beans or other), whereas a round perforated screen (lower screen) removes objects that are significantly shorter than rice (i.e., dust, husks, and such).

Keys to the performances of paddy cleaners are a) uniformity to feed, b) perforation size and shape, and c) air velocity. These determine the effectiveness of screening and aspiration and affect the throughput capacity of the machine.

B. Destoners

After paddy cleaners remove foreign materials ls and seeds that are a) wider than rice, b) shorter than rice, and c) less than rice, a process is requirde to remove objects, such as stones, mud, and even dense glass, which are more dense than rice (Chakraverty et al., 2003).

4) Moisture content

Moisture content (MC) has a marked influence on all aspects of paddy and rice quality. It is essential that paddy be milled at the proper moisture content to obtain the highest head rice yield. Paddy is at its optimum milling potential at a moisture content of 14% wet weight basis. Grains with a high moisture content are too soft to withstand hauling pressure which results in grain breakage.

5) Storage management

Storage systems that cater to relatively larger amounts of grains need to be efficiently and effectively managed to ensure maintenance of the quality of the stored grains. Storage hygiene is the preventive technical measure that maintains the quality of the stored seeds and prevents losses. Good storage hygiene is a prerequisite for successful storage. Seeds stored within a grains store should be hermetically sealed. That is the most important (IRRI, 2012).

The basic principles of storage hygiene are:

1. Always keep the store and its surroundings clean: a simple broom is the most effective and economical tool.

2. Always keep the grains cool and dry.

3. Always keep the store in good condition (IRRI, 2012).

6) Relative humidity

If the grain is stored in an enclosed stored environment (e.g., bag, silo, etc.), the surrounding grain, if it is well sealed, is not in free contact with outside air. In this case, the relative humidity of the enclosed air will reach an equilibrium with the moisture content in the grain. The final relative humidity of the enclosed air is often expressed by the 'equilibrium relative humidity'. The higher the grain moisture content of the stored grain, the higher the equilibrium relative humidity, and the higher the changes of mold development or loss of germination. In general, an equilibrium relative humidity inside the storage of 65% or less is considered a safe prevention against the development of molds (IRRI, 2012).

7) Temperature

Storage temperature is one of the most critical factors in insect reproduction. All insect species develop faster at their upper optimum temperature range requirements. While lowering the temperatures of the storage environment delays insect development and simultaneously increases insect mortality, this generally results in a decrease in the population growth rate. Temperature higher than the optimum range is lethal to insect development (Jocelyn et al., 1991).

Insects, being poikilotherms, are sensitive to large temperature changes in the environment. An increase or decrease in temperature outside the optimum range of 25–32^{o}C results in development delay, a drop in reproduction, and mortality at the end.

Insects are killed faster by heat rather than by cold treatment. Tolerance to heat treatment varies depending on the insect species, stage, and age of the insect and its physiological state. During heat disinfestation, the tolerance of the grain to heat should also be considered. As the limits for insect mortality and safety limit for grain quality are very narrow, it is important that the temperature and the period of treatment be monitored closely, lest grain become discolored, germinability impaired, and the gluten protein affected (Chakraverty et al., 2003).

8) Aeration

Temperature is major factor involved in regulating the level of pest activity in stored grain. When grain temperature is 15^{o}C or more, the insect pests develop quickly and cause heating and other related problems affecting the storage life of the grain.

Aeration is a part of the preventive management system, and the primary objective is to reduce the temperature of the grains in bulk storage. It involves forced movement of atmospheric air through stored grains by means of a fan, and has very little effect on the moisture content of the grain. The effectiveness of aeration is affected by the dockage, broken grains, and other impurities present in the grain (Chakraverty et al., 2003).

9) Storage time

The length of the storage period influences the amount of spoilage in the grain. Microbial growth is difficult to detect. Over long storage periods, this effect accumulates and can eventually be detected. In general, the longer the storage period, the lower the moisture content should be to ensure safe storage.

2.9 High temperature treatment of aging rice

Aging commences before harvest and continues as a time, temperature and moisture dependent index. Interactions amongst the variables are important. The resulting polynomial models suggest that rice aging is a complex process that is seen in the native rice grain, brown rice, milled rice, rice starch and cooked rice. Although the mechanism of rice aging is not fully understood, appreciation of the changes during storage is important in the evaluation of milling, cooking and eating quality (Zhou et al., 2002).

Rice aging is a process which involves changes in the physical and chemical properties of the rice grain. Changes in the colour of paddy, brown and milled rice are the main rice grain components which affect cooking and eating quality,while the overall texture of cooked rice stickiness remains unchanged during storage. As rice ages, the cooked rice texture becomes fluffier and harder (Zhou et al., 2002 and Chrastil, 1994). The texture of cooked rice grains has been shown as rice agesd. The texture of cooked rice grains becomes harder and less sticky than cooked fresh rice grains (Noomorhm et al., 1997).

Commonly, the people in Timor Leste consume rice in two forms: brown rice or regular milled rice from new harvested rice or aging rice. Some consumers like the cooking quality of aged rice for some months of storage and they prefer the grains to remain separate and firm after cooking. After rice is stored for 4–6 months in a warehouse, the texture of cooked rice becomes firmer and less sticky (FAO, 2010).

During storage, a number of physicochemical and physiological change occur, which is usually termed aging. These changes, which include pasting properties, colour, flavor, and composition, affect rice quality. As rice ages, cooked rice texture becomes fluffier and harder.