International Journal of Advanced Biotechnology and Research(IJBR)
ISSN 0976-2612, Online ISSN 2278–599X,
Vol5, Issue3, 2014, p474-489
http://www.bipublication.com

Effect of Degree of Milling (Dom) on Overall Quality of Rice - A Review

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[Received 11/05/2014, Accepted-23/08/2014]

ABSTRACT

Cereal grains, mainly rice, wheat, millets and maize are consumed globally in one form or the other. Rice is a staple food grain of India and is composed of husk, bran and endosperm. It is milled to a certain degree before consumption. After milling, amount of bran left on milled rice kernels is measured and is termed as Degree of Milling (DOM). Germ and bran layers are nutritionally rich but are removed during milling which affects the overall quality of rice. Higher the DOM, greater are the losses in the lipids, protein, fiber and ash content but the carbohydrate content increases with increase in DOM. DOM not only affects the quality but also the appearance of rice kernel, cumulative energy as well as head rice yield. On the other hand, low milled rice is harder thus require more cooking time. Rice grains milled to lesser degree have low length and volume expansion ratio, less cohesiveness and adhesiveness with low water uptake ratio. DOM also significantly affects the milled rice paste viscosities.

Keywords: Milling, Rice, Nutrition, Texture, Pasting, Energy, Head Rice Yield, Cooking

[I] INTRODUCTION

Cereals are grown throughout the world and are cultivated grasses grown mainly for the edible portion of their grain. Whole cereals, as well as their important fractions obtained after the processing contributes towards human diet as well as farm stockfooder [1]. Cereal grains are composed of endosperm, germ and bran. The major constituent of all the grains is starchy endosperm. Cereals constitute majority of daily sustenance in the form of rice, wheat, millet or maize throughout the world. Rice is a staple grain being consumed in its milled form by approximately half of the population of the world [2]. Its production all over the world accounts to 482.4 million tons in 2012 [3]. Rice grain has three main layers i.e. husk, bran and endosperm. Husk layer mainly constitutes lemma and palea making 20% of the weight of paddy. This layer helps in protecting the rice kernels from the attack of insects and fungi. Husk is removed during milling process; the rice so obtained is called brown rice which contains the bran layer and endosperm. The bran layer is made up of the pericarp, testa, aluerone layer and embryo (germ).

The acceptability of rice is influenced by various factors such as cultivars, climatic conditions, cultivation practices, harvesting conditions, treatments/processing, milling yield and cooking method [4]. Milling is the combination of various unit operations in order to produce well milled rice from raw rice. On the removal of bran layers, the storage life of milled rice is improved. Milling yield affects the producer's profit as well as its eating quality when cooked. It is very difficult to standardize a methodology for cooking rice as well as its extent of milling. There are variations in the personal choices from region to region like Japanese prefer sticky rice but Italians consume rice having high amylopectin content such as Baldo and Arborio rice. These varieties are short grained which releases starch during cooking making it a smooth and creamy risotto [5]. In the same way, partially milled rice with long grains is preferred by Americans, whereas scented Basmati or Jasmine rice is liked by Asians. Well milled white rice is preferred by people of Indian subcontinent [6]. As the amount of bran varies according to variety, conditions of environment and agricultural practices in the region, requirement of milling degree varies with different rice grains [7].

Brown rice is obtained by direct hulling of rough rice and is mainly composed of bran layers which comprise 6-7% of its total weight, 2-3% is embryo and major portion is endosperm comprising about 90% of the grain weight [8]. Other nutrient components such as lipids, fibers, proteins, vitamins and minerals are in higher proportions than white rice [9, 10, 11]. These nutrients are concentrated mainly in the germ and bran layers of the rice grain. During milling process, these nutrients are removed with bran and endosperm. White rice is commonly consumed worldwide but with growing health consciousness brown rice or partially milled rice has started gaining importance.

The present review is aimed at studying the effect of degree of milling on various properties of rice. The milling of rice at various degrees not only affects its overall quality but also affect the appearance and palatability of rice.

[II] MILLING OF RICE

Milling of rice involves various unit operations for converting paddy into white rice that has superior cooking quality [12]. Milling is a phenomenon of wear which involves removing material from solid surface either by mechanical action or by combinations of various actions such as rolling, impact or sliding [13, 14]. In most developing countries, maximum recovery in milling is around 7-8% but in India it is constrained to 4% by weight of brown rice [15, 16]. Commercial milling is a process consisting of various stages where firstly paddy or rough rice go through dehusking process and then the outer brown bran layer is removed during whitening process. In the final step, adhering bran is completely removed from grain surface and is known as polishing. Quality of milled rice is depicted by two important parameters i.e whiteness of the kernel and yield of head rice (HRY). Rice can be milled by two methods i.e. abrasion milling and friction milling. When the rice grain is made to revolve inside a milling chamber, then the grain which get in touch with the emery surface experience abrasion type of milling while grain which rub against each other experience adhesive type of wear. In rice polishing, generally a combination of both the types of wear is used as no pure form of milling has yet been discovered [17].

Rubber rolls were determined to be most suitable for laboratory scale milling operations as these increased the dehusking percentage but decreased breakage of rice kernels [18]. In a study, the performance of paddy husker for different rice varieties was analyzed while maintaining the physical attributes of the paddy. It was observed that rice husking parameters are dependent on size and shape of rice kernels and the speed of the impeller cannot be taken as a sole criterion for optimization of impeller husker performance [19]. This could be judged by low husked ratio even if the impeller speed was at its optimum. The quality of rice milling is affected by moisture content of paddy as well as rotor speed of the whitener [20]. Engineering properties were taken into consideration in order to study and evaluate the influence of various processing conditions on physical and mechanical properties of rough, brown and milled rice. It was observed that processing method used was not influenced by the variety of rice but by the type of processing method adopted to cause rupture of grains [21].

A significant effect on physical parameters of rice grains due to husking and milling operations was studied, evaluated and reported [22]. Various experiments were performed using different cultivars and different types of milling material such as plywood, iron sheet, rubber, glass and fiberglass. They found that the static coefficient of friction decreased with hulling and milling for different cultivars against all types of frictional surfaces used. Milling against rubber was found to be most effective for paddy but least for milled rice. In another study by [23] performance of perforated screen size and blade rotor clearance for whitening of rice grain was evaluated. The researchers concluded that the amount of breakage and whiteness decreased at first but later did not change significantly with increase in size of perforated screen. With increasing blade rotor clearance rice breakage and whiteness decreased but output rate increased significantly. There was no significant effect of change in perforated screen size on output rate.

[III] DEGREE OF MILLING

Milled rice quality is determined primarily by determining its Degree of Milling (DOM). It can be defined either by measuring the remaining amount of bran on surface of milled rice kernels or by determining the extent of removal of germ or layers of bran from brown rice kernels during various milling operations. There are many different methods used in studying the DOM (Table 1). Federal Grain Inspection Service (FGIS) used a subjective method to study DOM in which samples were evaluated by comparing them with interpretive line references generally used as standards by the graders. This method classifies rice into broad DOM categories i.e. under milled, lightly milled, reasonably well milled and well milled rice. Limitation with this method of analysis is that it did not provide any quantitative information regarding DOM. The United States Department of Agriculture (USDA) developed another subjective classification where samples are visually analyzed and compared on basis of specific DOM grades from “under-milled to hard milled” rice. However, DOM is rapidly and objectively measured in commercial practice using reflectance instruments such as milling meters or color meters. They can also be analyzed using light transmittance or with Nano-image Resonance (NIR) technology. Milling meters using both reflectance and transmittance measurements have been developed. One of such meter has been introduced by Satake (Model MM-liB) on commercial level. This meter analyze the milled rice samples and quantify their DOM on scale of 0-199 [24]. Measurement of milling degree of rice on basis of image analysis is dependent on the color of milled rice kernels. More white kernels correspond to higher degree of milling and are measured by pixel determination [25].

For objective measurement of DOM different methods have been employed. Out of those, most common method is based on calculating the loss in mass during milling process. A gravimetric measurement of DOM is done by using Equation 1 [26]. For this, samples in triplicate are analyzed and average of the data is used for analysis.

$$DOM = \left(1 - \frac{Wt.of milled rice}{wt.of brown rice}\right) * 100$$

Equation 1

A time consuming yet presumably more accurate method for determining DOM is petroleum ether extractions of Surface lipid Content (SLC) of milled rice. Measure of the lipid content gives the indication of remaining amount of germ and bran fractions on milled rice kernels. This is because the amount of bran and germ decreases with the progression of milling. A study showed high correlations between the surface fat concentrations and the readings of DOM taken by Satake milling meter (Model MM-liB). As the milling duration increases there is increase in the DOM but SLC and HRY decrease linearly [27]. In another study by [28] it has been shown that with the increasing DOM, time required for milling increased but the HRY decreased. To quantify DOM, thickness fractions for various rice kernels was evaluated using Satake milling meter (Model MM-liB) and an inverse relationship between HRY and DOM was reported [29].

[IV] EFFECT ON ENERGY CONSUMPTION OF RICE

Quantification of the level of bran that has been removed from kernels of the grain during process of milling is called DOM. It is mainly influenced by factors such as hardness of the grain, its size and shape, surface ridges depth, efficiency of milling and bran thickness [30, 31]. Greater energy is required in obtaining same level of DOM for hard grain in comparison to normal rice. There is a linear relationship between energy consumption and DOM (0-10%) for both short and long grain varieties of rice (Figure 1). In order to remove greater proportions of bran, longer milling time along with greater force was required. It showed that long grain varieties required lesser energy than short grain varieties. This slight difference in amount of consumption of energy may have come due to variation in grain thickness, hardness and shape of the kernels [32]. In contrast, [26] showed that short bold varieties had low specific energy consumption (ADT 37) as compared to long slender varieties (Pusa Basmati and Swarna). They also showed that for all the three varieties with increasing DOM specific energy consumption also progressed and then it became stable after a certain level of DOM depending upon the variety. The overall energy consumption of the grain is the sum of the energy consumed during milling process and the energy consumed during cooking. Brown rice showed higher overall energy consumption as compared to the milled rice. Although, to produce partially milled rice, a particular amount of energy is required which in turn help in reducing the amount of consumption of energy during cooking process [32]. The high energy consumption of brown rice may be due to the fact that they have not been given any pretreatments such as soaking. Thus, consumption of partially milled rice should be encouraged to conserve energy and to reduce environmental stack on rice life cycle.

[V] EFFECT ON APPEARANCE OF RICE

Color of rice is imperative for sensory as white rice or completely milled rice has more consumer acceptance as well as market value [33, 34]. Variations in the color of rice depend upon amount of bran present on rice kernels. Color of the rice kernels varies according to variety, conditions of environment and pre and post harvesting conditions [7]. In the studies of [35] it was reported that bran appears darker in color and rate of bran removal is dependent on the lightness or color intensity of the rice grain. The researchers also showed that the color intensity of bran varies with different varieties. Brown rice from the Japonica (Koshikari) variety showed higher intensity in color in comparison to Indica variety. Similar findings were reported [36]. During milling process, both the varieties tend to grow lighter in color. This shows that with the increasing DOM, the lightness value and intensity of color of different rice varieties increased [11]. A study by [37] reported that whiteness of highly milled rice kernels increases linearly with increasing amount of bran removal. Whiteness of the milled rice kernels can be measured using commercial whiteness meters. These meters measure the kernel whiteness in range from 0-100 generally termed as Whiteness Index. In this index 0 value correspond to black surface while 100 depicts the whiteness similar to the whiteness of magnesium oxide fumes [2].

Now days, whiteness is measured using Colorimeters. The color of the kernels is judged on the basis of three parameters i.e. L*, a* and b*. The L* value shows the lightness, higher L* value indicates more lightness. The a* value indicates red-green color, higher a* depicts more red color. The b* value correspond to yellow-blue color, higher b* depicts more yellowness. Rice flour of different DOM and water saturated butanol extracts were prepared [11]. Color parameters were studied using a colorimeter (Hunterquest, Model CQ/UNI-1600, Reston, VA, USA). The yellowness and the redness levels decreased from outer surface to middle endosperm of brown rice at DOM (0-15%). Once the bran and outer endosperm were removed with increasing DOM, the yellowness and redness of the middle endosperm did not vary with further increase in DOM of raw rice. This showed that the pigments in the middle endosperm were uniformly distributed. Effect of cooking on color characteristics of the grain with increasing DOM was also studied. At DOM (9%) cooked rice with residual bran showed increase in brightness and redness whereas yellowness was decreased as compared to raw rice. This may be due to increased water uptake by the cooked grains and leaching of pigments from grains to the cooking water. Bran pigments could also diffuse from outer surface to the endosperm during cooking. The cooking of rice having DOM higher than 9% showed constant brightness and redness but a decrease in yellowness was observed as a function of DOM.

[VI] EFFECT ON HEAD RICE YIELD

Main objective during milling process is to obtain maximum head rice yield with least consumption of energy [38]. The rice kernels which are three quarters or more in length as compared to length of original kernels obtained after complete milling is termed as head rice. Head rice is 2 to 3 times costlier than of broken rice. Hence, priority of rice milling industry is to maximize the quantity of head rice with preferred level of kernel whiteness [2]. Head rice yield (HRY) can also be defined as the ratio of weight of milled rice kernels obtained in percentage to the weight of rough rice or paddy in percentage [Equation 2, 32]. Mass loss and breakage during milling are affected by various parameters such as cultivar, shape of the kernel and thickness of aleurone layer [39].

$$HRY\ (\%) = \frac{wt.of\,milled\,head\,rice}{wt.of\,rough\,rice\,or\,paddy} \text{X } 100$$

Equation 2

The head rice yield for short grain was found to be greater in comparison to that of the long grain because during milling short grain varieties experienced less breakage than the long grain varieties [40]. During milling, higher breakage is caused due to low surface hardness which in turn leads to low quality and low recovery of milled rice [7]. A study showed that short grains were able to flow more easily in a milling chamber following friction type of milling as compared to long grains [16]. After milling, greater HRY was obtained in case of short grains due to lower degree of breakage. It has also been observed that lower the degree of milling, greater is the yield of head rice. In a study, Koshikari varieties of rice were subjected to low DOM (2-5%) and it was observed that it not only improved the HRY of the whole kernels but also reduced the consumption of energy required in the overall process. This also showed more retention of food nutrients such as lipids and dietary fibers in low milled rice [32].

[VII] EFFECT ON NUTRITIONAL COMPOSITION

Milling process bring changes in chemical composition such as the concentration of sugars, amino acids, vitamins, minerals and fats along with changes in biological activities such as amylase or peptidase activities [41, 42]. Rice is composed largely of carbohydrates 80%, with little protein 6-7%, minerals, fats, etc. The proteins present in rice are particularly nutritious, rich in essential amino acid lysine and hypoallergenic for use in foods. But nutrients in the rice kernels are not uniformly distributed. Certain nutrients like fats, vitamins, proteins and minerals are found in good concentration in germ and outer layers of endosperm i.e. bran portion of kernels [43, 9]. A study by [11] showed that about 84.2% of kernel proteins are concentrated in outer endosperm and upon milling further the concentration of proteins decrease. The researchers also found that 61% of the most of the minerals are present in bran fraction of the kernels whereas the core of endosperm fraction mainly consists of starch (84.6%) in the kernels. During milling operations, these nutrients are removed thus reducing the nutritive value of starch. The DOM has an effect on the concentration of nutrients (Table 2). The proximate composition depends upon the degree to which bran has been removed from kernel surface. The rice subjected to lower DOM could lead to more nutrition which can assure better health of the consumers. Some studies are not comparable in Table 2 because researchers have used different methods of expressing DOM and there is no standard formula available for inter-conversions.

7.1. Proteins

Rice proteins are located mainly in the bran and removal of bran during milling lowers its content in the remaining kernel. The protein content of brown rice decreases as a function of DOM indicating decrease in its concentration from surface to the endosperm. The protein concentration further decreases from outer endosperm to core of the endosperm. In a study, processing of brown rice to white rice resulted in 28.6% loss of proteins [11]. Milling of rice to higher degrees also leads to loss of essential amino acids like glutamic acid, lysine and tartaric acid. These amino acids are mainly responsible for providing good flavor and taste to rice while cooking [44]. The proximate composition of milled kernels is dependent on degree of bran removal during milling. The grain polished for 5 sec has significantly higher protein content (10%) than grain milled for 40 sec (7.9%); whereas the rice grain subjected to polishing time of 10-25 sec and 15-35 sec had similar concentration of protein [45].

7.2. Carbohydrates

Carbohydrate present in rice kernels is mainly starch which is mostly concentrated in the endosperm. Milling of rice to various degrees increases the starch levels because the bran and germ portion of the kernel is removed. Generally carbohydrates are measured by the amount of amylose present in the rice kernels. The amylose content increases with increasing DOM [46]. The components affecting the sweetness or rice umami taste are sugars i.e. glucose and sucrose [47, 48]. Carbohydrate content was determined in different ways by different researchers. Some researchers calculated it as whole and some have calculated it in the form of apparent amylose content (AAC) on wt/wt dry weight basis (Table 2).

7.3. Fats/Lipid Content

Surface lipid content or the fat content act as an important parameter in measuring DOM because, lipids are concentrated in the bran layers. Lipid content is measured by petroleum ether extraction which is time consuming but presumably an accurate method. It indicates the quantity of bran and germ remaining on the outside of kernel after milling because bran and germ decreases as milling progresses. During various DOM, the bran layers are removed to different degrees showing variations in the surface lipid content. Higher the DOM, more lipid content is lost. Oil content of rice milled for 5 sec was 0.98% which was reduced to 0.13% when milled for 40 sec [45].

7. 4. Ash/ Mineral content

Minerals are generally concentrated in bran layers of rice kernels which are lost during milling process. On removal of bran upto 15% DOM, the intensity of minerals remained steady indicating uniform distribution of minerals in the middle and core endosperm. During milling process, the losses of minerals reached up to 84.7% [11 reported by 49]. In a study by [50] different brown rice cultivar were milled and loss in iron content was measured. It was observed that due to milling processes, 25-84% of iron content was lost from different cultivars. Like other nutrients, selenium was also lost during milling. This observation was based on milling and analysis of 10 different rice cultivars by [49]. The study showed that physical parameters can be optimized to achieve desired level of milling with least loss of selenium content in white rice. As the selenium content varied with different brown rice cultivars, distribution of its content showed a non-uniform pattern from bran layers to endosperm. In general the content of selenium was significantly reduced for all rice cultivars showing a linear relation with DOM. Important functions of selenium include its antioxidant property, anticancer effects and ability to perform enzymatic functions, hence, making it an inevitable element in foods [51]. As, there are lots of varieties available in rice, many studies have been reported showing loss in mineral content with increasing DOM but its effect on various different cultivars is yet to be explored.

7.5. Moisture Content

Different rates of moisture absorption are exhibited by milled as well as brown rice [52, 32]. Milled rice has the ability to absorb water at a faster rate than brown rice because all the protective layers are removed during milling operations. This leads the endosperm portion of the milled rice to absorb more moisture [53]. Brown rice has surface lipids and wax content which do not allow water to enter the kernel and hence have reduced water absorption rate [54]. At various levels of milling, rate of water absorbed for different rice fractions was evaluated but not found significant [32]. Other findings also showed that on removing 1% bran from kernels of brown rice rate of water absorption increased in brown rice comparative to rice milled at higher degrees [55].

[VIII] EFFECT ON COOKING AND TEXTURAL PROPERTIES

Cooking is application of heat treatment to different produce making them edible and fit for consumption [32]. Cooking quality is another significant parameter generally influenced by factors such as type of cultivation, variety and post harvest conditions, milling degree and method of cooking being employed [37, 56]. Rice is consumed largely in the form of cooked whole kernels though methods of cooking vary throughout the world. There are generally two basic methods of cooking of rice with a slight distinction. One is the American (excess) method in which rice is cooked in ample amount of water and then it is drained off, another is the oriental method in which rice is firstly rinsed with water and then it is cooked in a measured amount of water [57].

Rice is said to optimally cooked when it reaches an end point i.e. when the rice kernels has absorbed water to the maxima or the white core of rice kernels has been gelatinized during cooking process [58]. Water uptake ratio is another imperative factor which is taken into consideration during cooking process and is influenced mainly by variety and cooked rice yield. Yield of cooked rice showed a linear relation with water uptake ratio. In a study by [17] it was observed a positive effect on water uptake ratio and negative impact on optimum cooking time and hardness with increasing degree of milling. Soft textured cooked rice is obtained due to high water binding capacity of the milled rice grain. The milling process removes the bran layer which facilitates the movement of water into the core of rice kernels during cooking. Water uptake and length expansion ratios are generally influenced by DOM [59]. In order to improve the cooking quality it is important to choose a suitable degree of milling for each cultivar which can help in reducing losses during cooking. The kernel size gets reduced during milling and gelatinization temperature at DOM (20%) decreased cooking time for different varieties of rice. The thermal properties of rice were found to be dependent of the variety and the conditions of processing which in turn also affect its cooking quality [60]. Some of the studies are reported in Table 3.

One of the vital objectives of milling is to produce milled rice of acceptable cooking quality i.e. high water uptake ratio along with high length and volume expansion ratios but minimum cooking time. The amylose content of rice plays a significant role in studying the cooking behavior of rice. Varieties of rice having high amylose content generally give harder texture during cooking than those having low amylose content [61]. Rice containing high amylose has longer chains in comparison to rice with low amylose content. On cooking, firmer texture of rice is observed in the varieties having long chains (high amylose content) and vice-versa [62, 63, 64]. Soft textured rice is generally obtained with rice having high water binding capacity on cooking [17]. At the same time, parboiled rice (rice which has been partially boiled in husk) with similar moisture content level was reported to have harder texture than untreated rice on cooking [65]. Parboiled rice on cooking retained good shape resulted in low solid loss during cooking in excess of water as well as was found to be less sticky [66]. Losses during cooking depend upon the severity of parboiling treatment given [43, 67]. Rice texture is an imperative indicator of rice quality and its acceptability by consumers [6].

Cooking as well as textural properties principally depends on composition of the cultivars rather than their physical attributes [17]. In rice, as we move to inner bran layers the hardness increases i.e. outer bran layers are harder than the inner layers. Whereas endosperm fractions obtained during milling were of equivalent hardness. As brown rice of long grain Puntal variety was milled to various degrees (0-25%), a non-linear relationship was observed between various degree of milling and the milling duration which further indicated differences in hardness of various rice fractions obtained [11]. Rice having apparent amylose content in high proportions had less cooking time in comparison to low apparent amylose content varieties. Grain thickness also influence the cooking and texture quality as grain having more thickness tends to have high milling degree, low amylose and higher cooking duration. This may be due to low water diffusion rate of thick grain and its bran layers. Rice milled to lower degrees are less adhesive and cohesive as they are hard and they take more time in cooking as well as yield low volume and length expansion as compared to rice milled to higher degrees [17]. Eating quality of white rice is generally considered better than the brown rice [68, 12, 69]. Another study by [70] also showed similar results as higher water binding capacity, viscosity, swelling power and lower optimum cooking time was observed with increased levels of milling. There are various other parameters which are affected by degree of milling and are listed in Table 3.

[IX] EFFECT ON SENSORY PROPERTIES

Nowadays, with growing health consciousness consumer's acceptability and choice are growing towards brown rice or those which are milled to lower degrees. Sensory properties of rice are chiefly affected by factors like rice variety, degree to which they are milled and processing conditions [71]. Effect of different levels of milling i.e. 8-15% on sensory properties of cooked as well as milled rice have been studied using texture profiling as well as sensory profile. Sensory analysis was found to be more judicious than instrumental profile in order to study parameters of taste, hardness, cohesiveness and degree of agglomeration [37]. A study by [44] showed that taste sensors can be used to distinguish the brown rice and rice milled to different degree in their raw as well as cooked form. For evaluating rice tastes, taste sensors having lipid membranes can be used. The taste sensors with negative or hybrid membranes were found to be most suitable for predicting umami taste of rice as well as free amino acid content of cooked rice. Brown rice contains high amounts of free amino acids, free sugars, proteins, enzymatic activities, stickiness and water uptake ratio than white milled rice. With reduced milling yields, peak viscosity, water uptake and taste components are also reduced. The study also showed that brown and milled rice having varied milling yields can be distinguished by using taste sensors than other physico-chemical methods. Studies on different tastes of foods have also been studied such as on soya bean paste, sake (rice wine), soya sauce, etc. Though, effect of DOM on compositional and physical properties have been widely studied but its effect on cooking, textural measurements as well as tastes are yet to be investigated. For this, new technologies should be developed and studied in order to increase the number of samples or tastes being analyzed by taste sensors at the same time.

[X] EFFECT ON PASTING PROPERTIES

Pasting properties are generally considered as important indicator in judging behavior of rice during processing. These properties are also affected by milling of rice grains at different levels. Pasting properties depends upon various factors such as the type of starch granules, swelling potential of starch granules and the amount of leached amylose into the solution [72]. Pasting properties specifically peak viscosity (PV) and fall viscosity (FV) are affected by DOM of different rice cultivars (Table 3). When the medium and long grain rice cultivars were milled at different DOM, loss in surface lipid content along with increase in pasting properties was observed. Within the same cultivar, highly milled rice showed higher paste viscosities in comparison to the low milled rice. This is due to the fact that highly milled rice has high starch content than the rice milled at low degrees [56]. Among different cultivars, the parameters of PV and FV of pasting properties and effect of DOM on these parameters are studied or measured by an amylograph or Rapid Visco Analyzer (RVA). A linear relationship between PV and DOM has been observed. The effect of DOM on peak viscosities of medium grain varieties was higher as compared to long grain varieties. Retrogradation (re-association of starch granules after heating) of high apparent amylose content was influenced by changes in DOM, retrogradation process increased rapidly on decrease of temperature resulting in shortening of distance in the direction of flow of rice paste [73].

Rice pasting properties were widely determined using amylograph but now days a faster method of RVA has gained importance due to small sample size requirement. This method is getting popular especially among the breeders which are working with limited amount of samples [74, 75, 76]. Effect of different cultivars and storage conditions on rice pasting properties have been widely studied and published [77, 78, 79]. On the other hand, milling of rice at various degrees and its effect on its pasting properties are yet to receive attention and more studies need to be done. As peak viscosities of different rice varieties increased with increasing their DOM [56], effect of cooking of rice on pasting properties of rice was also studied and it was found that instrumental hardness of grain along with their adhesiveness decreased with increasing the level of DOM. These properties were also affected by proximate composition of the grain under consideration [17]. Another study showed that for long grain cultivars, firmness of the grain as well as surface lipid content dropped with increasing levels of milling. The firmness of grains when cooked decreased from initial value of 110N to a final of 90N [57].

[XI] FUTURE STUDIES REGARDING DOM

Many factors have already been studied and explored to find out the effect of DOM on overall rice quality. But still, many researches are yet to take place in order to understand the complete behavior of rice grain when they are milled to various degrees. During milling, important parameters studied are kernel whiteness and HRY in determining optimum milling duration. The effect of milling among different varieties and its correlation with changes in HRY and whiteness have not yet explored and there is no quantitative information available till date. New techniques have been developed; one such technique is taste sensing operations. Sensory differences in rice milled to different degrees can be determined not only by physical methods but also by new techniques like taste sensors. Effect of cultivation and low levels of DOM on cooking as well as texture of rice grain are yet to be investigated and can give way to new research in this field of study. Effect of different levels of DOM, especially the amount of bran remaining on kernels, on pasting properties of rice has received little attention. Nowadays consumers are conscious and include environmental and moral criterion in order to choose food products, so it is essential to conserve the energy used during processing of rice along with its nutritional value.

[XII] CONCLUSION

This study is a review based on effect of various levels of milling on overall quality of rice grain. It showed that the higher the level of DOM, higher are the losses in the nutritive value of the rice grains because the lipid content, proteins, ash/mineral content and fiber are present in the bran layers and the germ of the rice kernels which are removed during milling process. Rice grain which are milled to lower degrees are more nutritious than the rice milled to higher degrees. Varying the milling degrees not only affect the nutritional composition but also affected the appearance, yield, physico-chemical and functional properties as well. Low milled rice were found to have darker appearance but the rice which are subjected to lower degrees of milling have reported to give higher HRY. Higher milled rice showed good textural and cooking properties in comparison with the rice milled to lower degrees. It was also observed that the DOM also affected the milled rice paste viscosity.

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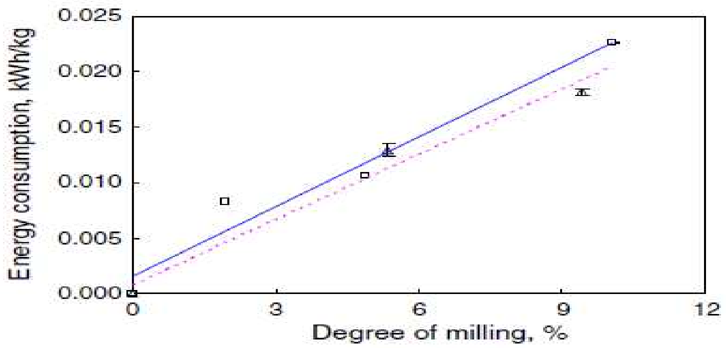

Figure 1: Relation between degree of milling and energy consumption of short grain (❑), long grain variety (Δ) [* Source: [32] Roy et al., (2008)]

Table 1: Different methods for studying DOM

S. No.	Method	Basis	Merits/Demerits	Reference
1.	Visual	Subjective	1. Inspection done by well trained officers 2. Low accuracy 3. Objectivity and long time	[80] Shiddiq *et al*, 2011
2.	Chemical analysis/ Optical Measurement	Subjective	1. Methylene blue is used for analysis 2. More time consuming	[25] Wan and Chanjiang, 2010
3.	FGIS	Subjective	1. Classified DOM into broad categories i.e. from well milled to reasonably well milled to lightly milled and lastly undermilled 2. Does not provide quantitative information to express DOM	[56] Perdon *et al*, 2001
4.	USDA	Subjective	1. Ranges milled rice from ‘undermilled’ to ‘hard-milled’ 2. Determined visually	[81] USDA, 1997
5.	Image processing	Subjective	1. Based on color of milled rice 2. Measured by pixel analysis 3. Faster and more accurate results	[25, 80] Wan and Chanjiang 2010; Siddhiq *et al*, 2011
6.	Milling meters/ SDM (Satake degree of milling)	Objective/ Optical	1. Use both reflectance and transmittance measurement to quantify DOM 2. DOM level on scale between 0-199 3. Zero level of SDM depicts brown rice and 199 represents snow-white fully milled rice	[24, 82] Archer and Siebenmorgan 1995; Chen and Siebenmorgan 1997
7.	Gravimetric Method	Objective	1. Most common method 2. Calculate mass lost during milling	[17] Mohapatra and Bal 2006
8.	Surface Lipid Content (SLC)	Objective	1. Measured by petroleum ether extraction 2. Indicates amount of bran and germ remaining on outside of kernel after milling	[83] Cooper and Siebenmorgan 2005

Table 2: Effect of DOM on nutritional properties of different varieties of rice

S.No.	Variety	DOM	Carbohydrates	Fat	Protein	Fiber	Ash/Minerals	Moisture	Reference
1	Puntal (Spanish harvest)	0-25 (%)	76.4-80.5	--	9.2-7.1	--	1.6-0.2	--	[11] Lamberts *et al*, 2007
2	Koshikari	0-10 (%)	26.1-35.6	1.0-0.4	2.1-2.5	1.3-0.5	--	69.1-61.5	[32] Roy *et al*, 2008

	IR 28	0-10 (%)	22-24.7	0.9-0.2	2.8-2.8	1.3-0.7	--	72.5-71.5	
3	Jasmine rice varieties	0-10.9 (%)	74.25-80.36	2.92-0.63	8.87-6.87	1.12-0.35	1.42-0.36	11.44-11.45	[84, 59] Payakapol, *et al*, 2011
4	Wells	20-50 sec	24.85-26.18 (AAC)*	0.52-0.19	6.65-6.19	--	--	--	Saleh and Meullenet 2007
	CL 161	20-50 sec	23.93-24.95 (AAC)	0.44-0.18	7.68-7.26	--	--	--	
5	Hom Mali Rice	0-15 (%)	16.2 - 20.4 (AAC)	--	--	--	--	--	[85] Imsil *et al*, 2011
	Low Amylose Rice	0-15 (%)	17.2 – 21 (AAC)	--	--	--	--	--	
	Intermediate Amylose Rice	0-15 (%)	21.8 – 25.5 (AAC)	--	--	--	--	--	
	High Amylose Rice	0-15 (%)	28.2 – 31.2 (AAC)	--	--	--	--	--	
6	Bengal	15-60 sec	--	1.19-0.3	--	--	--	--	[56] Perdon *et al*, 2001
	Orion	15-60 sec	--	1.2-0.4	--	--	--	--	
	Cypress	15-60 sec	--	1.21-0.25	--	--	--	--	
	Kaybonnet	15-60 sec	--	1.1-0.2	--	--	--	--	
7.	BRAZ	20-60 sec	3 %- 5% (Starch on % dry wt. basis)	0.617-0.264	--	--	--	--	[86] Chen and Bergmann 2005
	ORIN	20-60 sec	4 % - 7 %	0.509-0.216	--	--	--	--	
	CPRS	20-60 sec	5 % - 7 %	0.606-0.175	--	--	--	--	
	LGRU	20-60 sec	7 %- 13 %	0.375-0.143	--	--	--	--	
8	Basmati 370	5-40 sec	21.1-24.1 % (AAC)	0.98-0.13 %	10-7.9 %	--	--	--	[45] Karim et al. 2002

* AAC= Apparent Amylose Content. All composition values are in percentage.

Table 3: Effect of DOM on various parameters of rice varieties

S. No.	Variety	DOM	Parameter	Range	Reference
1	Swarna	3-16 %	O C T	16-22 min	[17] Mohapatra and Bal 2006
	ADT 37	2.5-18 %	O C T	20-24 min	
	Pusa	2-13 %	O C T	14-16 min	
	Swarna	0-20 %	V E R	2.14-3.5	

	ADT 37	0-20 %	V E R	2.25-3.97	
	Pusa	0-20 %	V E R	2.12-3.66	
	Swarna	0-20 %	L E R	1.36-1.58	
	ADT 37	0-20 %	L E R	1.49-1.67	
	Pusa	0-20 %	L E R	1.53-1.72	
2	KhaoDak Mali 105	0-10.9 %	P V	251.23-434.53	
	KhaoDak Mali 105	0-10.9 %	H N	13.35-5.66 N	[84] Payakapol *et al*, 2011
	KhaoDak Mali 105	0-10.9 %	D G	59-85 % (Approx.)	
3	CL 161	20-50 sec	H R Y	53.10-55.17 %	
	Wells	20-50 sec	H R Y	55.23-57.53 %	[59] Saleh and Meullenet 2007
	CL 161	20-50 sec	S L C	18-44 %	
	Wells	20-50 sec	S L C	19-52 %	
4	Hom Mali Rice	0-15 %	A S V	6.1-7.1	
	Low Amylose Rice	0-15 %	A S V	6.1-7.5	
	Intermediate Amylose Rice	0-15 %	A S V	4.6-5.6	
	High Amylose Rice	0-15 %	A S V	2.5-1.4	
	Hom Mali Rice	0-15 %	G C	82.4-64.5 (mm)	[85] Imsil *et al*, 2011
	Low Amylose Rice	0-15 %	G C	80.6- 58.8 (mm)	
	Intermediate Amylose Rice	0-15 %	G C	60.1- 46.8 (mm)	
	High Amylose Rice	0-15 %	G C	49.5- 34.5 (mm)	

* O C T: Optimum Cooking Time; V E R: Volume Expansion Ratio; L E R: Length Expansion Ratio; P V: Peak Viscosity; H N: Hardness; D G: Degree of Gelatinization; H R Y: Head Rice Yield; S L C: Surface Lipid Content; A S V: Alkali Spreading Value; G C: Gel Consistency