Chapter 2

Review of literature

This chapter reviews the reported studies on rice, broken rice, rice noodle, rice starch, physical modification of starch, utilization of modified rice starch in rice noodles manufacturing that are reported in literature.

2.1. Rice in India and Assam

Since more than 5000 years, people have been eating rice (*Oryza sativa* L.) that belongs to the Gramineae family [145]. The majority of people around the globe consume rice as a staple diet, and Asia accounts for around 95% of the world's production of this important cereal crop [20, 66]. In some Asian nations, rice provides as much as 80% of daily calories and 20% of protein intake [16]. India and China each make up 19.5% and 28.7% of global manufacturing, respectively. In 2019–2020, India produced approximately 117 million tons of rice [94]. Andhra Pradesh, Assam, Punjab, Bihar, Chhattisgarh, Haryana, Orissa, Tamil Nadu, Uttar Pradesh and West Bengal are the major rice-producing states in India. In terms of rice production, India is currently self-sufficient, and it ranks among the top exporters of rice in the global market [101]. The North-eastern part of India is highly suitable for rice cultivation. Particularly, Assam is regarded as one of the places where rice was first cultivated [40] and boasts of a vast array of rice varieties with wide range of amylose content viz. waxy, low amylose, intermediate amylose and so on. Here, short bold and medium slender grain cultivars with moderate amylose content, soft gel consistency and intermediate gelatinization temperature are preferred for regular consumption. Depending on the amount of amylose of milled rice, rice can be classified as glutinous or waxy rice with 0-5% amylose content, very low amylose with 5-12% amylose content, low amylose with 12-20% amylose content, intermediate amylose with 20-25% amylose content, and high amylose with 25-33% amylose content [61].

Assam has around 25.3 million hectares of total coverage for rice production, which is approximately 70% of total agricultural land [40, 98]. In the state, there are four major categories of rice cultivars: i) Sali rice, also known as winter rice, is transplanted in June or July and harvested between November and December; ii) Ahu rice, also known as autumn rice, is grown between March and April to June and July; iii) Boro rice, also known as summer rice, is grown during November/December and harvested during May/June and iv) Deep-water or bao rice transplanting occurs from April to May and harvested between December and January [40]. Out of many rice varieties grown in Assam, *Ranjit* is one of the most popular, high yielding Sali variety covering more than 50% area [29, 49], and is commonly consumed as cooked rice. However, information on the quality characteristics, functional properties and usage of rice varieties of Assam and their by-products in processed foods is scanty.

2.2. Broken rice

Broken kernels are milled (polished, unpolished, or under-polished) kernels that are shorter than 3/4th of an unbroken kernel in length. It is the second major by-product of rice milling in small mills accounting to up to 25%. This causes the rice industries to suffer a significant financial loss because the price of broken rice is only one-fifth of the price of whole grains [78]. It is mixed with the local super or premium rice at least at a quantity of 5% and consumed by the lower-income earners in rural areas [70]. The amount of broken rice symbolizes unprofitability for rice industry and hampers the characteristic functionalities of rice for its ultimate application in food processing. There are different factors responsible for the generation of broken rice such as immature paddy grains, moisture content of the paddy, pre-processing before milling (drying), chalkiness, climatic changes in terms of relative humidity, temperature during storage, infestation, degree of milling, type of cultivar, type of mill, etc. [24].

Rice grains are not uniform in terms of composition and properties throughout their length. Due to this reason, the broken rice generated from different positions of the whole rice grains are most likely to possess different sizes and thereby have dissimilar properties. Therefore, the functionality of rice flour obtained from broken rice will primarily depend on the sizes of the broken rice. It has been noted that brokens differ in functionality from head rice, particularly they show softer gel, lower peak viscosity, and lower final viscosity as compared to head rice [132], which decreases with decreasing size of brokens.

Mukhopadhyay et al. [95] investigated the impact of fast moisture adsorption on total fissuring, number of fissures per kernel, and the particle-size of the brokens. The authors also evaluated the functionalities of the resulting brokens after size fragmentation. For the study, paddy was stored the at 9, 11, 13, 15 and 17% initial moisture content (IMC) and reconditioned to 12% moisture content prior to milling. Results revealed that as the IMC decreased, there was rise in the level of fissuring in the kernels (both in terms of fissures in each kernel and the number of kernels with fissures). Different cultivars produced different quantity of large, medium, and small sized brokens. Regardless of IMC, the head rice showed significantly higher pasting properties which decreased with the reduction in size of brokens. Thus, the authors recommended to identify the end use of size-fractioned brokens.

Bruce et al. [24] assessed the pasting characteristics of different fractions of parboiled and non-parboiled brokens. They size fractionated the broken rice using US sieves no. 10, 12 and 20 corresponding to 2.00, 1.68 and 0.84 mm sizes respectively. Larger brokens showed better pasting profile and had lesser protein than smaller ones. Pasting properties of brokens mixture of large and small fractions in 1:1 ratio was not significantly different from small and medium brokens.

Bruce et al. [25] studied the effect of size, mixing of different broken fractions and temperature of drying on the physicochemical properties of brokens. The results were consistent with their previous study in [24]. The protein content of smaller brokens was higher as compared to larger brokens. The peak viscosity and final viscosity of whole kernels were higher than of the two categories of brokens. They came to the conclusion that broken rice flour should be classified according to size in order to ensure uniformity in its pasting qualities. Hence, separating the different sized brokens will be effective to investigate the ultimate properties of rice flour produced from similar sized brokens and eventually enable the determination of their final applications.

Usman et al. [120] examined the extraction of starch from many varieties of broken rice at different pH and temperature. Maximum recovery of 95.4% starch from KSK-133 rice was achieved. There is an increasing demand of rice flour in the market for use in a number of food products and pharmaceuticals, cosmetics etc. Utilising rice flour and rice starch obtained from broken rice can be immensely reasonable and economic.

The application of broken rice in the rice industry in limited [100]. However, due to its hypoallergenicity and gluten-free status, brokens and rice flour have recently seen a significant growth in demand. Rice is primarily used to produce gluten free biscuits targeting the celiac patients [110]. Broken rice has been also used in breakfast cereals [41, 46], baby foods [97], and for producing a variety of foods made with rice flour, including noodles, rice sweets and rice cakes [72], and new formulations, such as flour blends and modified starches [41]. Further processing of broken rice can be a solution to increase the economic value of the rice so that it does not only become waste but is utilized properly [46]. This is where the utilization of broken rice instead of head rice becomes reasonable and more economically justifiable due to its lower price [23].

2.3. Rice noodles

The majority of the cultivated rice is consumed as cooked rice, with a small quantity being utilized as feed and an ingredient in processed goods [145]. The second most popular rice product after cooked rice is rice noodles in Asia [48] after wheat noodles [58], which has eventually spread to other parts of the world also. They are well liked by consumers in the present times in order to keep up with the hectic pace of modern living. According to historical evidence, rice noodles are thought to have originated in China during the Qin dynasty between 259–210 B.C. (> 2000 years ago) [84]. Noodles are now not only widely produced in China, but also in Japan, Korea, Malaysia, Philippines, Thailand, Vietnam, India and Pakistan, [85].

Noodles are loved by many people of all ages. Rice noodles are becoming more popular in various Southeast Asian countries, according to reports. According to Grand View Study Inc.'s market research, in 2014, the rice noodle market in Asia Pacific and Europe was worth USD 1.69 billion and it is anticipated that this amount will progressively rise through 2022 to reach USD 3.6 billion [51]. It is worth noting that Chinese and Indian markets are expected to drive global noodle market expansion. The world's largest regional market for noodles is believed to be in Asia [111]. Indians consume a considerable amount of pasta and noodles, as evidenced by the fact that dried pasta accounts for 75% of the market's value and 62% of its volume. Consumer awareness of living a healthy life is one of the major reasons driving the growth of this market for rice noodles. Urbanization has increased the need for convenience foods like noodles while also causing consumer behaviours to change as the working population has grown. Thus, we can understand that noodle has become one of the inevitable components of our diet.

Noodles made from rice are much more delicate in texture and flavour than wheat noodles as they are gluten-free. Though rice noodles are not a health-promoting food, but still, they can be a healthful addition to a well-balanced diet and make for a great gluten-free alternative. For people with celiac disease, rice noodles represent another gluten-free eating choice. When the supply chain is further improved, it is anticipated that this trend will become even more pronounced [83]. Rice noodles can be classified as fermented or unfermented depending on the pre-treatment process used for the raw materials [58]. Rice noodles can also be categorised as being fresh, frozen, semi-dry, dried and instant. Unlike dried and instant rice noodles, which have a constant shelf life, fresh rice noodles are often cooked at home or on a small scale. Both a main dish and a side dish can be made with rice noodles. They can be cooked in a broth or stir-fried with meats and vegetables, or they can be boiled in the broth and used as soup noodles. Due to commercial advancements in rice noodle production technology and effective distribution methods, individuals may now obtain rice noodles everywhere in the world [58].

Numerous elements, including rice species and composition, raw material pre-treatment, processing techniques, and environmental considerations, might influence the quality of rice noodles. Their quality is now being researched, along with the elements that affect it, ways to make rice noodles better, and how novel additives work on the overall quality of noodle [75].

2.3.1. Rice varieties used for rice noodles

Rice noodles are usually manufactured from rice grains having high amylose content (>25% amylose) [57] or (>28% amylose) [85]. These rice grains give high gel texture (hardness), tensile strength, and stretch easily without breaking, all of which are desirable characteristics during the manufacture, handling and packaging of rice noodles. When noodles are produced from intermediate amylose rice (22-25% amylose), they have softer texture [28]. The two basic ways used to make rice noodles are extrusion of dough to vermicelli, and sheeting dough to create flat noodles [48]. Rice proteins are unable to create continuous viscoelastic dough the way wheat gluten can. It is usual practise to pregelatinize a portion of rice flour in order to produce a binder for the remaining flour [48]. Noodle processing typically entails many steps: ageing, washing, soaking and grinding the rice into slurry, followed by pregelatinization/gelatinization, extrusion/slitting, cooking, cooling to promote retrogradation, sterilising, drying, and packaging. The standard quality indicators for rice noodles, such as rheology, cooking, sensory, texture, and digestive qualities, will differ significantly depending on the processing method used.

2.3.2. Raw materials functionality for rice noodles

To create a high-quality product, it is crucial that the raw materials have the proper and sufficient functional and processing qualities. Since rice does not contain gluten, the rice noodle quality is completely determined by the physicochemical qualities of starch [139]. The functionalities, procedures, and desirable quality of the raw materials are assessed initially to determine its suitability for noodle production. Rice flour physicochemical properties facilitate proper understanding of their applicability and potentiality to be used in the rice noodles production.

Chemical composition of the rice grain inevitably has significant effect on the rice noodle quality. Starch is the main component that gives the structure, texture to the rice noodle, and determines the end product quality [85]. There is a strong correlation between amylose and how well rice noodles are received. Rice varieties containing high percentage of amylose, rigid gel consistency, and low gelatinization temperatures are desirable for manufacturing rice noodles. Noodles with a soft texture are produced from rice flour with an intermediate amylose concentration. Such noodles cause significant solid loss in the cooking liquid. Very low amylose content flour produced noodles with a very poor texture, hence it is not utilised to make noodles [60].

The structural arrangement of starch in rice and mung bean noodles were studied [92]. It was found that amylose contributed to the formation of a continuous 3D network by being closely linked to one another via junction zones in the lack of gluten. It is reported that the insoluble amylose is responsible for restricted swelling of starch granule, reduced cooking loss, and improves the high temperature tolerance during cooking of starch-noodles [35].

Yoenyongbuddhagal and Noomhorm [139] evaluated the physicochemical properties of Thai rice (32-36%, amylose) flour and their relation to the qualities of rice vermicelli made from those varieties. Gel hardness of the flour gel is quite suitable for predicting overall vermicelli quality as it well correlates with cooking as well as textural properties of vermicelli. Rice flour with low protein content produces flavourful, tender and cohesive rice noodles. Presence of lipids is beneficial to form amylose-lipid complex, inhibit long term retrogradation, and quickly settle noodle structure [90].

It was reported that amylose content, solubility, rice flour swelling volume and breakdown as obtained in rapid visco analyser (RVA) are reliable predictors of cooked gel texture and may be used as a substitute for assessing the texture of rice noodles. [21]. The hardness, tensile strength, and extensibility of the noodles all positively correlate with the pasting temperature [53]. Since RVA pasting parameters and its gel texture [21, 139] and damaged starch content [53] were closely related to noodle texture and cooking loss, they may be used as an alternative approach to predict the quality of rice noodles in the initial phases of rice breeding. Swelling power and solubility of flour or starch is recommended to be tested at 92.5°C to forecast the eating quality of noodles owing to a good estimation of actual noodle processing at that temperature [35].

2.3.3. Effect of particle size of rice flour

Noodle quality has been found to get influenced by the particle size of the flours used for their production. Hatcher et al. [54] studied the effect of particle size (>132, >110, and >85 μm) and damage starch on dough properties and noodle quality of Canadian Western red Spring wheat grade No.1 variety. For each particle size, higher starch damage led to high cooking loss. For each level of damaged starch, smaller particle size caused reduction in cooking loss.

Effect of rice flour particle size (20-200 mesh) prepared by wet milling on the vermicelli qualities was evaluated by Yoenyongbuddhagal and Noomhorm [140]. The cooking and texture of rice vermicelli was both influenced by flour particle size, but the water absorption index was unaffected. Bigger particle sizes generated more cooking loss in vermicelli and cause less palatability. Vermicelli made from flour sized less than 200 mesh was suitable and had acceptable texture.

The physicochemical parameters of rice flours made by dry milling with sizes 63, 80, 100, 125, and 140 μm and their impact on the texture of laksa noodles were investigated [99]. The lowest gelatinization temperature and the highest water absorption capacity, pasting attributes and gel hardness were observed in the 63 μm size flour. The textural characteristics of laksa noodles were improved by reducing the rice flour particles size and noodle made from 63 μm size flour showed the better textural and sensorial qualities.

Qian et al. [109] have reported that rice flour particle size, 160–180 μm is suitable for rice noodles. Too large particle size can make the products' eating quality gritty, while too fine flour can cause transportation issues in the production line.

Farooq et al. [44] found a negative relation between the particle size of flour and the rate and extent of digestion. Moreover, due to amylose-lipid complexes, the non-waxy rice flours demonstrated a lower digestibility rate than the waxy rice. Fine particle size (< 50 μm) flours of all the varieties showed significantly higher swelling power and solubility. Out of all varieties, the waxy rice flour had higher swelling index and solubility.

Kim et al. [68] found that due to their increased mechanical and thermal exposure, rice flours with smaller particle sizes (80-100 μm) showed more severe starch degradation. Their strong water affinity may have resulted from their larger surface areas. The pasting viscosities of the samples were all significantly lower in 140-250 μm size flour. In contrast to samples of rice-zein with smaller particle sizes, those with greater particle sizes showed lower storage modulus (G') and higher tan δ. Among the noodles, the samples with 100-140 μm particle size showed significant reduction in cooking loss and higher tensile strength.

Nagai et al. [96] examined the effect of four different particle sizes (> 420, 212–420, 53–212, and < 53 μm) of nonglutinous rice flour on noodle quality. The flour with 53- 212 μm particle sizes had the least amount of damaged starch. Noodles prepared from 53-212 μm showed desirable textural properties.

Thus, different particle size of rice flours has been reported for manufacturing rice noodles from different varieties of rice and has resulted in wide variation in the quality of cooked noodles. Therefore, determining the functional, pasting and gel properties of different particle size of rice flour in relation to the noodle quality becomes necessary.

2.3.4. Characteristics of rice noodles

The visual characteristics of cooked and raw rice noodles are taken into account while determining the qualitative attributes of noodles. The main criteria for judging rice noodles are their noodle qualities, which include uniformity of size, shape, texture, and colour as well as their nutritional, textural, and cooking qualities [5, 43]. Low solids loss during cooking and a pleasing texture [139] and less cooking time and white colour [112] are desirable characteristics of rice noodles. After cooking, the noodles must still be firm, chewy, and non-sticky. Rice noodles of high quality have consistent, straight strands, a translucent white colour, and no broken strands [48].

2.3.4.1. Cooking quality

Cooking quality is the most important element for noodle consumption and noodle processing. Cooked noodles should have a reasonably strong bite, a firm and smooth surface. Determining the optimum cooking time is the foremost step in evaluating the cooking properties of noodles. The noodles are cooked by infrequently stirring them in hot water. Squeezing the rice noodle strands together between glass slides and noting the time it takes for the white core, which signifies the completion of cooking, to disappear, the ideal cooking time is determined. Usual cooking time for rice noodles is reported to be 5-9 min [6]. The water absorption index, swelling power, and gelatinization temperature of the flour affect the noodle cooking time [5]. Two significant variables that affect the quality of cooked noodles are cooking loss and swelling index. Significant starch solubility causes cloudy cooking water, limited cooking tolerance, and a sticky mouthfeel, hence high cooking loss is undesirable. On the other side, a low swelling index denotes a low capacity to hold water thereby yield hard and coarse noodles.

2.3.4.2. Texture quality

The examination of texture is a crucial factor in finalizing the overall quality of cooked noodles that demonstrates consumer acceptability [53]. The force required to chew the cooked noodle and its mouthfeel are experienced as the noodle's texture. Texture analyser determines the texture and tensile strength, and a relatively high hardness is desirable. Tensile testing evaluates the sample's breaking strength and elasticity since these characteristics provide a clue to its performance during cooking, providing and insight into the noodles' cooking quality and cooking tolerance. Noodle texture attributes and tensile strength are positively correlated with amylose content. Rice noodle texture is affected by the rice variety, their chemical composition, physicochemical properties, and flour particle size [43, 68, 99, 139-140]

2.3.4.3. Sensory quality

The mouthfeel of the cooked rice noodle is one of the crucial factors in deciding consumer acceptability of the product, and it is typically analysed via sensory analysis. However, the evaluation of the noodles by consumers happens first in visual inspection considering the colour, appearance and absence of cracks or fissures in the noodle [55]. Different sensory attributes such as aroma, appearance, taste, texture, slipperiness, hardness, smoothness, elasticity, tooth packing and overall acceptability were opted by different authors for analysis the sensory properties of rice noodles [62, 68]. However, the sensory evaluation of rice noodles is rather tricky because of differences in consumer preference for the sensory attributes. Thus, proper knowledge of the sensory characteristics is essential and therefore, the sensory evaluation is made by trained or semi trained sensory panels [6]. Fari et al. [43] reported that the sensory panellists liked hard non-sticky noodles, regardless of the flavour. Thus, as compared to other qualities, the flavour is an insignificant attribute of rice noodle quality. Kraithong and Rawdkuen [71] reported that higher scores of textural attributes such as hardness, firmness etc. resulted in lower scores for overall acceptability of the commercial Thai rice noodle. They had also reported that the sensory acceptability of the rice noodles was positively correlated to pasting properties, particularly final viscosity and setback viscosity.

2.3.5. Improvement of rice noodle quality

Flour of fresh rice grains has limited gel-forming quality due to the presence of alpha amylase and yields noodles with inferior eating quality, which cannot be used for commercial rice noodle preparation. To meet the optimum requirement, aging of rice (restricts the alpha amylase activity) for 1-3 years is followed in industries which is a time-consuming process [144]. Moreover, rice noodles prepared from intermediate rice variety yield softer texture with high cooking loss and broken rates. Therefore, the rice flour or starch extracted from the rice can be exposed to suitable modification to improve their noodle making quality. The modified flour or starch can be used as a substituent in the formulation of the composite noodle blends to produce rice noodles with improved eating quality.

2.4. Rice starch

Starch comprises around 90% (db) in milled rice and more than 75% (db) in broken rice [145]. The two main components of rice starch are amylose (20–30%) and amylopectin (70–80%) [31]. However, some varieties, typically waxy may contain 97-100% amylopectin [113]. The relative quantities of amylose and amylopectin, as well as their distribution and magnitude of presence, are the key factors affecting the composition of rice starch and have a significant effect on the physicochemical and textural properties. In contrast to amylopectin, a branched polysaccharide made up of short α-1,4-linked chains connected by α-1,6 connections, amylose has a linear chain of α-1,4-linked D-glucose units. While amylose and amylopectin branch points make up the amorphous portion of starch, the outside amylopectin chains form double helical structures by hydrogen bonding, resulting in an ordered crystalline region. Rice starch shows A-type X-ray diffraction (XRD) pattern and degree of crystallinity in rice starch is comparatively low. Rice starch with higher amylose content has lower swelling power and solubility as compared to rice starch containing low amylose.

Rice starch granules have angular and polygonal shape that possess smooth surface. Rice starch has a single granular size distribution and exists as compound granules having a diameter around 150 µm that is a cluster of 20 to 60 granules. A wide variety of amylose and amylopectin ratios, low allergenicity, lack of gluten, good digestion, high acceptance by the consumer, bland flavour, small granules, and white colour are some of the general characteristics that make rice starch unique compared to other starches [73].

2.5. Modification of starch

The functional features of starch, such as those that relate to cooking, pasting, water holding capacity, etc., are significant determinants of its intended usage [76]. However, starch in its natural state may not possess the desirable qualities necessary for a particular type of product. Since the starch pastes are unstable at various temperature, shear stress, and pH conditions [117] and results in low paste clarity, undesirable gels, weak-bodied paste, with cohesive texture and rubbery consistency when cooked [12]. Thus, their use in industries is limited. Modification of starch with suitable method brings new functional properties which are not found in its native form. When choosing a native starch for a chemical or physical modification, the qualities necessary for a specific application, the starch's availability, and costs are all important considerations.

Commonly, starch is modified by chemical, enzymatic, and physical methods. Physical modifications bring changes to the characteristics of starches without affecting the free three OH groups at carbon numbers 2, 3, and 6 on the glucose units of starch molecules. It is a treatment that use heat, pressure, steam, sound, osmotic pressure and electricity to cause disruption of the glycosidic linkages causing de-polymerization [11]. Since their functional qualities are better than those of native starches, starches modified by physical means have become crucial components of processed foods, also they are regarded as safe and environmentally friendly. The starch granules may either be conserved or completely disordered and this brings about changes in functional properties.

2.5.1. Heat moisture treatment (HMT)

HMT is a hydrothermal treatment that involve use of restricted moisture levels that is below 35% (w/w) and heating above glass transition temperature at about 84-120 ^{o}C for a specified period of time (15 min to 16 h) [56]. However, there are a few studies, which even used higher temperature (<84 °C and >120 °C) [9, 47, 115], time (<15 min and >16 h) [86, 125] and moisture content (>35%) [115] as specified above.

HMT was first studied on corn starch in 1944 [113]. Subsequently, HMT was studied to modify other starches. During HMT moistened starch is kept inside a sealed container that prevents the moisture escape when heated. It builds up pressure inside the sealed bottle due to heating increasing the thermal energy that is converted into kinetic energy by water molecules [113]. As a result, the amorphous region of the starch is changed to a more flexible state from a glassy state [129]. HMT cause an increased interplays between the starch chains, which leads to a rupture in the crystalline structure and a separation of the double helical structure with subsequent reassociation [113] because the α-(1,6)-glycosidic linkages in amylopectin branches are more susceptible to HMT [129].

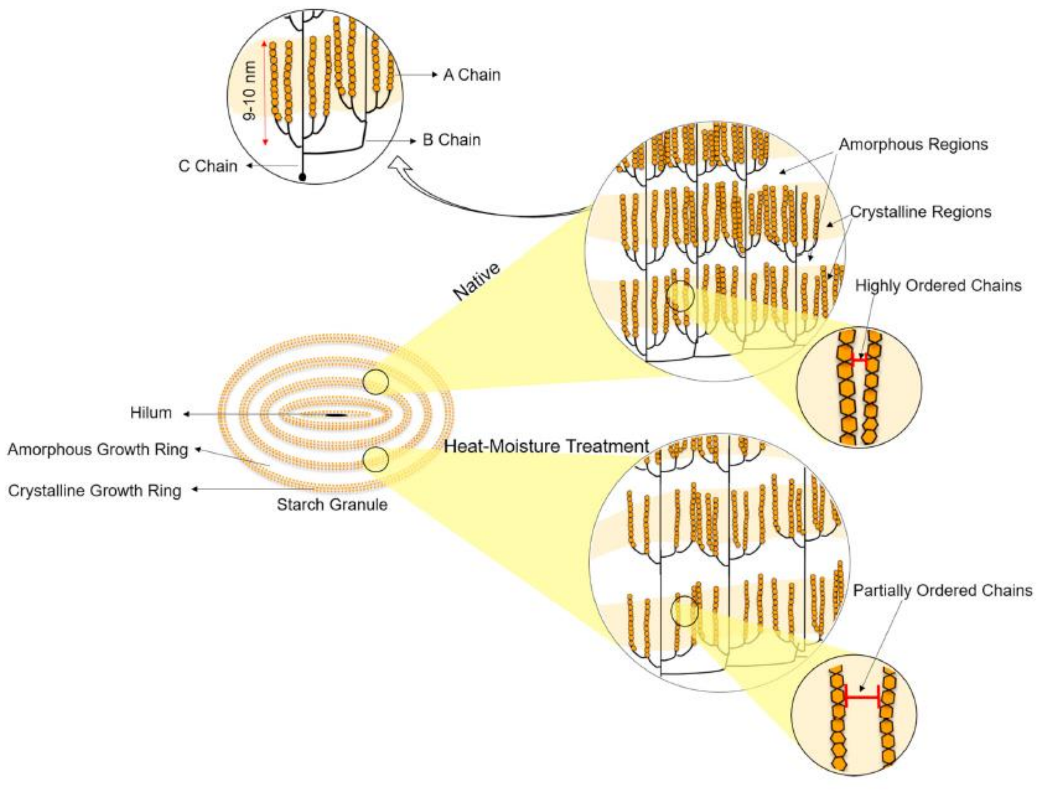

Fig. 2.1 Molecular structure of native and heat moisture treated starch [113].

The fragmented crystals then rearrange themselves. In order to change the physicochemical properties, HMT enables many facets of the starch granule structure to be concurrently altered under regulated temperature and moisture conditions. However, the source and composition, typically amylose content effects the extent of changes after HMT [93]. The key benefits of HMT over other starch modification methods (chemical and biological) are its efficiency, flexibility to different heat sources, low cost, and lack of chemical residue production [113]. These benefits make it a very alluring methodology for enterprises, particularly the food industry. However, HMT may associate with non-uniform heat distribution during treatment that results in partial gelatinization of starch making it difficult to treat the starch at large scales [106].

2.5.1.1. Effect of HMT on swelling power and solubility

Amylopectin probably thermally degrades as a result of HMT as indicated by a drop in amylopectin content but an increase in amylose content [104]. Swelling power is the property of amylopectin. Swelling power have been observed to decrease on HMT than native starches [50, 64, 135]. Although the created HMT starches still retained lower swelling than their respective native starches, in some cases, it increased when the treatment temperature and moisture content were increased [118]. HMT has conflicting effects on starch solubility; data point to both increases [15, 19] as well as decreases [2, 50, 64, 103, 135]. The disruption of the amylose/amylopectin array within granules may be the cause of decline in swelling and solubility indices. The intrinsic interactions between molecular chains may strengthen under heat-moisture circumstances, impeding the hydration of free OH groups. During HMT, clusters of side chain of starch granule could be packed closer together, which helps create a rigid crystalline structure that prevents water from permeating into starch granules [102, 129]. Moreover, amylose exudation and solubility can be reduced by starch swelling being hindered by an HMT-induced amylose-lipid complex [129].

2.5.1.2. Effect of HMT on pasting properties and gel hardness

Compared to native starches, HMT starches typically displayed a higher pasting temperature or time, and lower peak, trough viscosities and breakdown [15, 32, 50, 64, 103]. Peak viscosity is positively connected with starch's ability to swell, and reduced swelling power of HMT starch may prevent amylose from leaking out and intensifying viscosity [142]. HMT causes increase [28] as well as decrease [50, 57, 118, 142] of the setback and final viscosity. HMT starches often have better heat and shear stabilities than native. There are reports of an increase in RVA gel texture after HMT [57]. The greater hardness of the gel was assumed to be due to enhanced cross-linking among starch chains, particularly in amorphous region during HMT. These facilitated the creation of more connection zones in the gel’s continuous phase, increasing its hardness [57].

2.5.1.3. Effect of HMT on X-Ray Diffraction (XRD) and relative crystallinity (RC)

HMT can cause alteration in the native crystalline packing of starch granules. HMT usually does not change the A-type structure [56]. Starches with B-type (tuber starch) structure may be transformed to A-type (cereal starch feature) or mixed (i.e., A+B-type, legumes + tuber + root starch feature) polymorph as a result of HMT [77, 125]. The changes in the XRD peak intensity and RC of starches after HMT varied as per many reported works (increased, decreased, or remained unchanged) [37, 47, 56, 116, 141]. However, the increase in the peak intensities noted in A-types starches during HMT is attributed to the shifting of double helices within the crystallites and cause more close packing and ordered structure than native starch because the number of hydrogen bonds that links the adjoining helices increase. On the contrary, unordered packing of crystalline region causes decrease in the intensity. Formation of amylose-lipid complex (V-type crystalline polymorph) with the endogenous lipid in starch after HMT has been reported which is mostly associated with the higher level of single helices as shown in Fig 2.2 [126-127, 129].

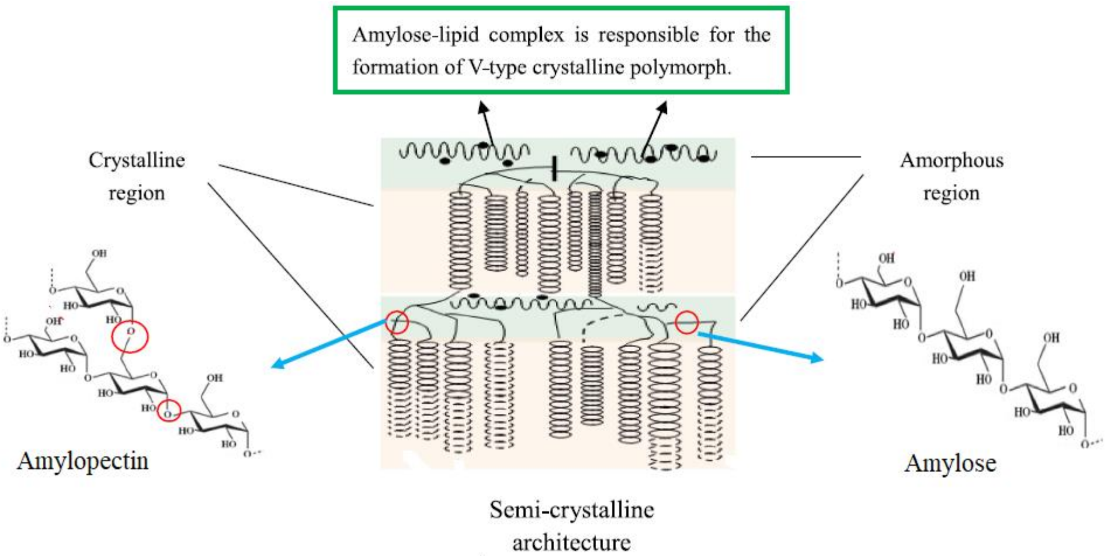

Fig. 2.2 Formation of amylose-lipid complex in cereal starch after HMT [129].

2.5.1.4. Effect of HMT on morphology

The changes brought about by HMT in the morphology of starch differ significantly. Various morphological changes irrespective of the starch source reported on HMT include presence of granular form and Maltese cross [3], indistinct changes to granule size, hollowing at centre of the granule [8, 50, 65], decreased birefringence with less distinct quadrants [32, 34, 105], surface indentations of granules [64, 106], and agglomeration of granules [8, 136], surface fissures [93, 102]. However, many of the studies did not find significant changes in the granule morphology after HMT [10, 22, 64].

2.5.1.5. Effect of HMT on gelatinization properties

HMT starches show an upward increase in gelatinization temperature relative to native starch, including the onset (T_o), peak (T_p), and conclusion temperature (T_c) of gelatinization, in addition to a large range of gelatinization temperature. [37, 56, 79]. These effects have been linked to the increased interplays between starch polymer chains (amylose-amylopectin and amylopectin- amylopectin) and/or starch-lipid complexes in amorphous regions, which in turn causes a decrease in mobility of starch chain within amorphous area and an elevated crystallite melting temperatures [52, 126, 130, 133]. The high range shift in gelatinization temperatures implies improved thermal stability [129]. Moreover, HMT showed biphasic broadening of differential scanning calorimetry (DSC) peak that corresponds to inhomogeneous heat transfer during the treatment of starch [106].

2.5.1.6. Effect of HMT on enzyme hydrolysis

According to the source of the HMT starch and the process conditions, the sensitivity to enzymatic degradation may be enhanced, decreased, or unaffected [56]. Most data indicate that HMT causes reduction in rapidly digestible starch (RDS) and minor to moderate increases in the content of thermostable slowly digestible starch (SDS) and resistant starch (RS) [32-34, 50]. HMT starches have reported an increase in amylose content which can undergo rapid retrogradation to form RS [104]. The formation of undigested RS is due to partial gelatinization of starch and its subsequent retrogradation, which takes place during processing. HMT can also cause the development of amylose-lipid complex, an RS type 5 and retrograded starch (RS type 3). Englyst et al. [42] originally used the term “resistant starch” to refer to a small portion of starch which could not be hydrolysed by pullulanase and α -amylase.

Most notably, gelatinized HMT cereal starches typically have higher SDS and RS levels than their gelatinized native counterparts [80]. The majority of the RS and SDS consists of a semi-crystalline area made up of double helices with DP in the range, 13-24. The preferential occurrence of recrystallization in long-chain amylopectin or amylose could hasten the production of RS [67]. SDS may be likely to form through the interplay of external A and B_1 branches with maximum DP ≥ 15.5 [91].

2.5.1.7. HMT on rice starches

The physicochemical properties of rice starch of long grain and waxy grain modified by HMT was studied [114]. Starches were HMT modified at 110 °C with varied moisture contents in the range of 20-40% for 8 h. HMT starch modified using 20% moisture content showed typical A-type pattern whereas starch modified using 30 and 40% moisture contents showed rise in peak intensity at 2θ = 20° indicating the V-type pattern (amylose-lipid complexes). Usually, the gelatinization temperatures increased at higher moisture content. Moisture content above 20%, starches showed biphasic thermogram where the second peak corresponds to inhomogeneous distribution of moisture during HMT. Pasting properties drastically dropped at 40% moisture content owing to the development of disordered crystallites in the granule.

The effect of HMT at moisture content of 15%, 20%, and 25% on rice starch with varied amylose content was studied [39]. The treatment was conducted at 110 ºC for 1 h. HMT reduced swelling power, solubility, RC and pasting parameters. The rate of enzymatic hydrolysis increased as the moisture content of the treatment increased.

The effects of HMT on RS content, morphology, thermal, and textural attributes of rice starches of different amylose content was investigated by da Rosa Zavareze et al. [38]. It was reported that the resistant starch content of all three types of rice starch increased linearly with increased moisture content. The gelatinization temperature increased with decrease in enthalpy of gelatinization. Starch granules were more and more agglomerated in all HMT starches. Interestingly the gel formed by rice starches of high and medium amylose content showed higher hardness at 15 and 20% moisture content.

Pasting, textural, thermal properties and morphology of rice starch and flour treated with HMT was evaluated [108]. The samples were moistened at 20, 25, and 30% moisture content followed by heating at 100 ºC for 16 h. HMT showed greater impact on paste, gel texture, and DSC gelatinization properties of rice flour than rice starch. Rice protein had major effect on the differences in the various properties that were investigated.

Arns et al. [10] examined HMT on starch by producing HMT starch in two ways; first, it was applied to paddy grains directly and the starch was isolated later, secondly

HMT was subjected to the starch previously extracted from the untreated paddy. The starch extraction efficiency from the HMT treated paddy is reduced due to the enhanced starch-protein interplay. The pasting attributes of both HMT starches were lower than the native counterpart. HMT induced high thermal stability and mechanical strength. No significant morphological changes were visible under scanning electron microscope (SEM).

Van Hung et al. [122] investigated the rice starches modified by HMT and annealing (ANN) by subjecting to *in vitro* and *in vivo* digestibility. HMT caused increase in RS content which is remarkably more in starch with higher amylose content whereas ANN caused increase in SDS and RS of starch with lower amylose content. Both the modification methods reduced the GI of rice starches. While GI in native starch was in the range 68.9-100, it was in the range of 61.2-88.9 in HMT starch and 21.2-43.9 in ANN starch.

Wang et al. [127] reported that HMT can cause starch degradation and eventually led to changes in the crystalline or semi crystalline structure, short-range ordered structure and double helix. Post HMT, starch undergo molecular re-arrangement that cause agglomerated and aggregated starch molecules transforming part of RDS to SDS and RS.

Yang et al. [137] studied the structural and digestion properties of starch isolated from polished rice grains exposed to HMT. HMT caused partial gelatinization in the rice starch. Greater resistance to enzyme hydrolysis was observed in the starch having high amylose content owing to reinforcement of the associations among the polymer chains of starch granule.

Van Hung et al. [121] investigated the physicochemical and digestibility of starches extracted from unpolished rice grains with and without heat moisture treatment. HMT was subjected to the unpolished rice at 20, 25 and 30% moisture content and 100 ^{o}C or 120 ^{o}C heating temperature. HMT at high temperature and moisture content supressed granular swelling and paste breakdown without changing the crystalline pattern. Starch treated with 30% moisture content and high temperature showed reduced enzyme digestibility and increased RS content.

Yang et al. [138] reported that the increase in moisture content of starch upto 30% during HMT caused rise in the amylose content whereas further increase in moisture content at 70% tended to reduce the amylose content. Gelatinization temperature, transmittance of paste and starch digestibility increased with increasing moisture content whereas swelling power and enthalpy reduced. Rice starch with high amylose content caused reduction in swelling power, long and short-range molecular order structure, gelatinization temperature and increase in resistant starch portion. The study concluded that the high amylose rice starch treated at moisture content below 30% promotes enzyme resistance to hydrolysis whereas starch treated at higher moisture content (> 30%) promotes past transparency and solubility.

Bao et al. [17] experimented to elevate the RS content of rice starches with intermediate to high amylose content using HMT, citric acid and pullulanase enzyme. The HMT modified starches showed high amylose, gelatinization temperature range, pasting properties and RS content than native whereas decreased relative crystallinity.

Enhancement of RS content of starch with high amylose content by HMT was studied by Lee et al. [74] using response surface methodology. HMT could increase the RS content of rice starch from 32.1 to 46.4% at optimized condition. The XRD peaks at 22.7^{o} and 24.2^{o} were merged upon HMT at higher temperature.

2.5.2. Osmotic pressure treatment (OPT)

OPT is another physical modification method that involves heating of starch in saturated sodium sulphate salt solution at high temperature followed by washing and drying of starch. Salts can be reused after dehydration thus the waste generation can be prevented. Although this method uses salts (inorganic compounds), it is considered as a physical modification method since it does not cause alteration in the chemical structure (does not replace the free hydroxyl groups of glucose molecules) of the starch and fulfil the definition of a physical modification method.

It was first conducted by Pukkahuta et al. [106] in potato starch to produce modified starch having similar functionality as obtained by HMT. The osmotic pressure of the salt solution can be determined by an osmometer or calculated by the mathematical formula as given below:

$$\pi = MRT \qquad \text{Eq. (2.1)}$$

where, π= osmotic pressure in kPa, M= Molarity of the solution, R= Gas constant, 8.314 J $K^{-1}mol^{-1}$, T= Temperature in Kelvin

OPT caused plasmolysis (inward folded structure) of starch granule. Pasting profile of the starch was highly affected as evident by the indistinct parameters except final viscosity, which increased when treated at 105 ^{o}C whereas a decrease of the same was exhibited when heated at 120 ^{o}C. Native potato starch transformed from B-type to

A+B and A-type structure. Homogenous heat distribution was indicated by narrow DSC peak with elevated onset, peak and gelatinization temperature in OPT starch, whereas inhomogeneous heat distribution was reported in HMT as indicated by biphasic broadening of DSC peak. Amylose content increased via OPT at 120 ^{o}C for 15 min but decreased after 30 min and 60 min.

Jane [59] suggested that the rise in gelatinization temperature in presence of sulphate ions was due to the formation of hydration shell with water. As a result the free water molecules required for granule swelling reduces resulting in restricted gelatinization. The OH groups of glucose units in the starch granule repel the sulphate ions that inhibit diffusion of ions inside the granule.

It was reported [4] that higher gelatinization temperature in presence of sulphate ions (SO_4^{2-}) starch swelling is hindered thereby inhibiting the gelatinization at elevated temperature. Moreover, the salting-out ions such as SO_4^{2-} increased the gel strength of the starch gel.

Varavinit et al. [124] evaluated the impact of OPT on the crosslinking reaction of tapioca starch using 10, 20, and 40% of sodium chloride and sodium sulphate. Pasting temperature increased when osmotic pressure was increased for both the salts. Peak and final viscosity increased initially with the increasing in osmotic pressure when sodium sulphate was utilised, but they later reduced with further pressure rise. Breakdown was decreased with higher osmotic pressure. Both peak and final viscosity decreased linearly with the increasing osmotic pressure whereas breakdown was not detectable. These features of rice pastes were ascribed to the crosslinking reaction. Pasting parameters decreased with higher osmotic pressure when sodium chloride was used. Thus, crosslinking reaction can be enhanced by the use of osmotic pressure exerted by the added salts.

Pukkahuta and Varavinit [105] studied the changes in the characteristics of sago starches modified by OPT and HMT. XRD pattern showed the transformation of C-type to A-type on OPT and HMT. They suggested that OPT starch is more appropriate for large scale production due to uniform heat distribution. Another study on OPT by the same author on corn starch also reported suitability of OPT for large scale production. They also have observed similarity in the properties of OPT and HMT corn starches [107]. Pukkahuta et al. [105-107] in any of their work, however, did not clearly explain how the starch component act as semipermeable membrane and the mechanism of OPT.

A comparative study on modification of taro, potato and corn starch was carried out by Karmakar et al. [63] where OPT, cross-linking and acetylation were separately performed on potato, corn and taro starches. OPT starches from corn starch and taro starch treated at 15, 30 and 60 min showed increase in swelling volume, amylose content and amylose leaching with increasing time of treatment.

Fasuan and Akanbi [45] standardized the OPT on *Amaranthus viridis* starch using artificial neural network by considering the amount of starch, saturated salt solution (Na_2SO_4) and reaction time to yield high quantity of total and free amylose and amylose-lipid complex. Starch (149.04 g), sal solution (248.40 ml), and reaction time (19.41 min) were established via artificial neural network to obtain 36.38% total amylose, 28.01% free amylose and 8.37% amylose-lipid complex. Amylose-lipid complex is RS type 5 that has the potential to improve the colon health and can lower GI.

Marta et al. [88] examined the changes in physicochemical, pasting and crystalline properties of breadfruit (*Artocarpus altilis*) starch modified by OPT. Agglomeration of granules after OPT was observed under SEM. OPT-treated starch was transformed from B to A-type pattern and RC decreased. Pasting temperature increased and all the pasting parameters decreased after OPT. Swelling volume decreased whereas solubility, water absorption and syneresis increased.

Marta et al. [89] conducted OPT on corn starch and observed increase in amylose content after OPT. OPT starch showed layered strips on the surface of the granules under SEM. Relative crystallinity decreased and V-type starch was detected at $2\theta=20^{o}$. 1047/1022 ratio and 995/1022 ratio decreased indicating less ordered structure. Pasting temperature increased and all the values of pasting parameters decreased after OPT. Gelatinization endotherm changed towards higher temperature range. OPT caused reduction in swelling volume and rise in solubility, gel strength, and syneresis.

It Is reported that amylopectin of starch is concentrated on the outer layer of the starch granule [7] which plays the role of a semi-permeable membrane. This amylopectin region is permeable to water and electrolytes but nonpermeable to the amylose in the inner region of the granule [88].

Atkin et al. [13] reported that when the starch slurry (5%) is heated it swells and formed a translucent envelope on the granule surface during the early stages of gelatinization (Fig. 2.3). Granules of high amylopectin starch swell by 200% in size, and the surface layer of the granule creates an envelope around the interior starch polymers that have been disrupted. High temperatures cause high amylose starches also to form envelopes even though they swell insignificantly. The granule envelope is primarily composed of amylopectin. The internal starch components get released only when the granule rupture and collapse at critical stress point as the gelatinization is complete. However, the ruptured granule envelope forms a web-like network which is termed as "ghost remnant".

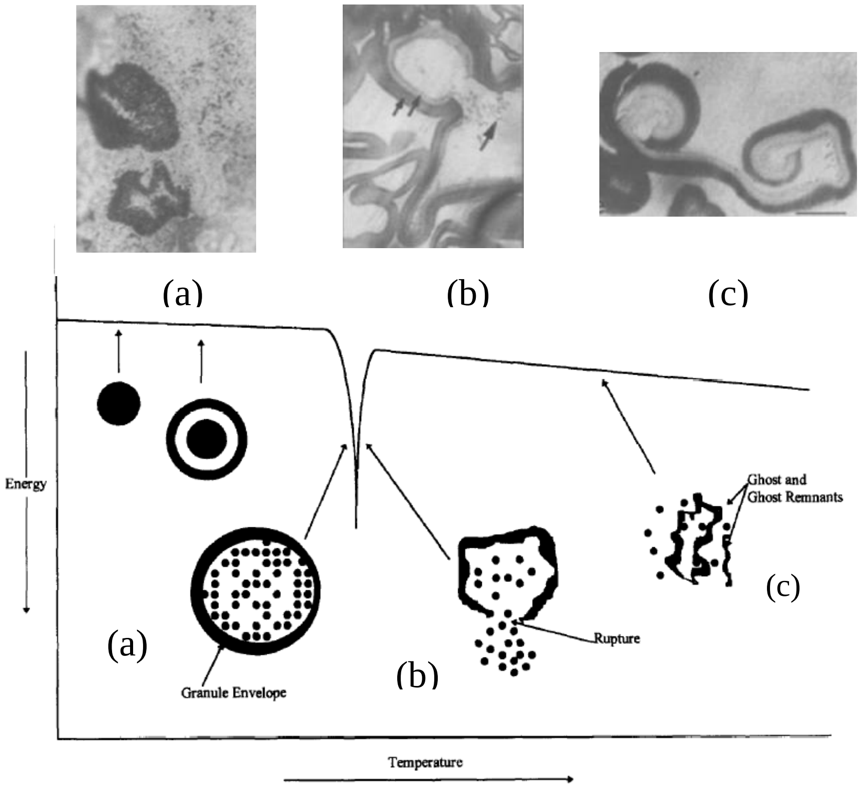

Fig. 2.3 The model of starch gelatinization, formation and degradation of granule ghost plotted in a hypothetical DSC curve. Images of starch envelope formation (a), rupture of starch (b) and coiling of starch envelope after rupture (c) [13].

The semi-permeable covering of granule possesses structural resemblance to retrograded amylose [119]. Conjoining of those retrograded amylose form honeycomb like three-dimensional network where the enlarged granules operate as active filler. Wang et al. [131] also supported findings of Atkin et al. [13] and stated that the granule envelope contains higher molecular weight amylopectin which in fact consists of smaller part of A chains and larger part of B3+ chains. This granule envelope is formed due to molecular entanglement during swelling and acts as a semi-permeable membrane like surface. Starch absorbs more water with rise in temperature and the internal granule components become more mobile, but cannot leach out through the granule envelope until it is ruptured.

BeMiller [18] reviewed the work on OPT by Pukkahuta and concluded that the actual phenomenon or process under which starch is heated during OPT is in fact not very clear. The changes observed in OPT starches were caused due to heating of the granules in a kosmotropic solution, which restricts swelling of granules and `thereby gelatinization is restricted rather than osmotic pressure of the solution because starch granules lack a semipermeable membrane. However, they do not have any experimental representation to support their claim so far. Based on his review work on OPT reported that OPT is another hydrothermal treatment. Moreover, they concluded that the changes brought about by the OPT were similar to the changes caused during HMT.

It was seen that starch treated with OPT showed similar properties as HMT starch. OPT has been studied in various starch samples such as, corn, potato, sago, taro starch etc. as a single physical modification process and in combination with other chemical methods. OPT is also considered to have uniform heat distribution during the treatment. However, physical modification of rice starch by OPT and its effect on the characteristics of the modified rice starch are not yet investigated.

2.5.3. Dual modification of starch

Single modifications of starches have failed in some food uses due to low stability during shearing at high temperature. Therefore, the necessity of alternate or another modification to overcome the shortfalls arises. Due to this, dual modification has been developed in an effort to enhance the characteristics of single modified starches [12]. Dual physical modification of starch combines two physical treatments. The properties of dual modified starches generally lean more toward the second effect than the first, though occasionally they have physicochemical characteristics that combine both modifications [11].

HMT has been studied in combination with various other modification methods (Table 2.1). However, its effect in combination with OPT is not reported. When HMT was combined with different modification methods the changes in the resulting starch varied.

Table 2.1 Dual modification of starches from different sources by HMT in combination with various modification methods.

Starch source	Modification type	Findings	References
Rice, cassava pinhão,	Single and dual HMT	• Low setback and final viscosity • Low hardness of the rice starch gel. • At 120 ^{o}C, single or dual HMT appeared to partially gelatinize rice starch. • High peak gelatinization temperature was caused by dual treatment. • C-type to A-type pattern conversion occurred in pinhão starch. • The HMT of rice at 120 ^{o}C exhibited the highest decrease in RC.	Klein et al. [69]
Indica rice	Dual modification by enzyme and HMT	• After single and dual alteration, the temperatures and enthalpy of gelatinization increased. • A combination of B-type and V-type XRD patterns was seen in indica rice resistant starch (IR-RS) products. • Crystallinity increased remarkably. • Reduced the digestibility of indica rice.	Zhou et al. [143]

		• Body weight, blood sugar, organ indices, and serum cholesterol levels were all considerably affected by IR-RS produced by dual modification.	
Waxy rice	Single HMT, ANN and dual HMT-ANN and ANN-HMT	• Both single and dual treatments resulted in an increase in gelatinization parameters. • In contrast to HMT, ANN showed an increase in RC and short-range order. • SDS content was higher on HMT and ANN-HMT whereas RS content dropped in all treated starches. • The molecular weight of treated starches decreased after modification.	Zeng et al. [141]
Pinhão	Single and dual modification by HMT, ANN and sonication treatment (SNT)	• The peak viscosity of ANN and HMT starches could be raised by applying SNT as a second treatment. • HMT promoted the greatest influence on gelatinization temperatures and enthalpy whether applied alone or in combined modifications. • Native starch, single ANN and SNT starches displayed CA-type crystalline pattern	Pinto et al. [103]

		but dual modified starches showed A-type pattern. • Dual modification caused increase in RC. • The apparent cracks, notches, or grooves did not exist in the pinhão in the ANN, HMT, and SNT starch.	
Brown rice	Single HMT, ANN and dual HMT-ANN and ANN-HMT were applied in the flour followed by starch isolation.	• ANN had higher pasting temperatures, setbacks, and final viscosities than native starch did. • After modifications, the range of the gelatinization temperature rose and the enthalpy reduced. • The relative crystallinity was unaffected by ANN, but it dropped with HMT and dual alterations. • Single and dual modified starches lowered RDS while increasing SDS and RS in cooked starch granules. • ANN-HMT caused slight crushed structure on the granules unlike other. • Decrease in apparent amylose content was observed in single and dual modified starches.	Bian and Chung [22]

		• Molecular weight of amylopectin decreased after single and dual modification.	
High amylose, normal, and waxy rice	Dual acid (acetic acid, citric acid and lactic acid) and HMT	• Dual starch modification resulted in starch with decreased pasting viscosity. • Crystalline structure did not change. • After the treatment, the values of RS increased from 18.5 to 23.9% in HMT starch and from 30.1 to 39% in dual modification. • Citric acid showed highest impact on the RS formation. • Reduction in swelling power with higher solubility occurred.	Van Hung et al. [123]
Corn	Dual extrusion (ET) and HMT (EHMT)	• Higher thermal stability was achieved after EHMT. • The gelatinization temperature range broadened, while the enthalpy rose following EHMT. • ET caused reduction in relative crystallinity. XRD pattern changed from V-type to V+A-type. • EHMT caused increase in	Yan et al. [136]

		SDS and RS. • EHMT reduced swelling power and solubility.	
Potato	HMT, high hydrostatic pressure (HHP) and their combination	• Peak viscosity, final viscosity and setback rose significantly after HHP. • Dual modification raised the transition temperatures. • Affected the relative crystallinity. • Modified starch exhibited low digestion rate which decreased with increasing moisture in the HMT. • Increased swelling power. • Dual modification can be utilised in the creation of foods with a reduced GI.	Colussi et al. [36]
Cow pea	Dual HMT-ultrasound treatment (UST)	• Prolonged heating reduced the pasting viscosities. • The treatments used had no effect on the gelatinization properties. • None of the treatments used altered the granule shape or XRD patterns. • Remarkable increase in SDS was observed in HMT-UST starches. • HMT and HMT-UST caused a decrease of amylopectin branching degree.	Acevedo et al. [1]

2.5.4. Utilization of physically modified flour/starch in rice noodle making

Use of chemically modified starch along with some hydrocolloids is commercially practised for making rice noodles. At present, there is an increasing demand for natural treatment for rice flour and starch that can bring desirable changes in its physicochemical and functional characteristics. Several means of physical modification of rice flour can develop various desirable properties of the starch.

HMT rice flour and starch have been studied by some authors for making composite rice noodles and starch noodles. Since HMT can suppress the granule swelling, restricts gelatinization and increase thermal stability of starch at elevated temperature and increases the gel hardness, HMT treated starch and flour showed improvement in desirable properties required for rice noodle making. The decrease in swelling index and exudation of amylose as well as the increased stability at variable heat and shear that occur due to HMT are all advantageous for the production of noodles. Some of the notable works on the uses of physically modified flour and starch of rice in the rice noodle production are discussed as follows.

Rice flour was treated by HMT and the physical and physicochemical properties were evaluated for suitability of modified flour to produce rice noodles by Lorlowhakarn and Naivikul [82]. Rice noodles were prepared with partial substitution of HMT rice flour to native rice flour in three different proportions viz. 5%, 10% and 20%. HMT considerably decreased the pasting parameters except pasting temperature. Colour determination revealed that the treated rice flour showed higher redness and yellowness than the native flour. Tensile strength of noodles prepared from 10% HMT flour substitution was comparatively higher.

Hormdok and Noomhorm [57] used physically modified starch in addition to rice flour for rice noodle preparation. In their study, they employed two hydrothermal treatments on rice starch, viz. ANN and HMT. They analysed the modified starch with respect to its applicability in rice noodle making by considering the properties such as pasting property, gel texture, thermal property and functional properties. HMT and ANN increased the gel hardness of rice starch from 49.82 g in native to 61.23 g in HMT starch with 20% moisture content and up to 60.38 g in ANN starch. Composite rice noodles prepared by substitution of hydrothermally treated rice starch for flour exhibited parameters which are closure to commercial noodles. They concluded that hydrothermal treatment of rice starch could be an alternative to prolonged ageing of rice grains.

Cham and Suwannaporn [28] optimized the HMT and ANN on high amylose rice variety by applying response surface methodology (RSM) with face-centred central composite design (FCCD). The impact of treatment parameters, such as moisture content, temperature, and heating time, on rice flour pasting properties (setback and final viscosity), storage modulus, and gel hardness were investigated. HMT showed higher response than ANN in all parameters. The authors reported that ANN is best suited for fresh rice noodle preparation where softer texture is required whereas HMT was more suitable for semi-dried and dried noodles.

Gluten-free alkaline noodles were prepared using HMT rice flour of three different varieties (CN 1, KDML 105 and RD 6) blended with untreated rice flour at 30, 40, 50, 60 and 70%. Cooking loss of noodles made from 30% HMT-KDML 105 and 30, 40, 60 and 70% HMT-RD 6 were not significantly different. Sensory score of firmness of noodles containing 30% HMT-KDML 105 and HMT-RD 6 were higher than other blends and significantly similar [27].

Application of hydrothermal treatment (HTT) to produce hydrothermally treated glutinous rice flour (HTT-GRF) for quality improvement of gluten-free noodles was reported [26]. HTT caused decrease in peak and final viscosity viscosities however with higher breakdown which indicated its lack of stability at usual cooking temperature. Less setback as noted in HTT-GRF implies the less retrogradation tendency. Dough prepared using HTT-GRF had high extensibility and thus enabled the preparation of noodles requiring remarkably less cooking time. However, the textural and sensory properties were far inferior than the control (wheat noodle). Therefore, improvement of the noodles using HTT polysaccharide mixture containing HTT-GRF and xanthan gum was explored which yielded in noodles with higher sensory scores.

Choi and Koh [30] produced noodles using four different types of annealed flours prepared by ANN at room temperature and 50 ^{o}C for 3 h with and without removing the water-soluble fractions. They investigated the impacts of different ANN conditions on the cooking, texture and sensory aspects of cooked rice noodles. Reduced cooking loss and enhanced sensory properties with improved textural attributes can be achieved in noodles when flours treated by annealing at room temperature combined with water-soluble fractions removal was used.

Wang et al. [128] examined the effect of annealed rice starch (10, 20, 40, 60 and 80%) in the manufacture of starch noodle and their eating quality. Annealing caused significant reduction in solubility, swelling power and pasting viscosities that helped in the improvement of eating quality of rice starch noodle. The finest overall attributes were found in the noodles produced with 40% (w/w) substitution of annealed rice starch.

Modification of rice starch by physical methods involving higher temperature has shown to increase the RS content. Employing this kind of single or dual modification techniques, may enhance the usability of the rice starches for product development such as rice noodles. As rice has high GI, incorporation of starches modified by physical treatment, might be used for developing rice noodles with high RS and lower GI. RS consumption has been shown to reduce insulin release and manage blood glucose levels, hence preventing diabetes [134]. After escaping the small intestine undigested RS get partly fermented in the colon producing short chain fatty acids which help in maintaining colon health. Baghurst et al. [14] proposed that 20 g of RS per day is required to deliver colon health advantages. However, any official recommendations in terms of RS intake are not available [81].

Relying on the above review of literature it was hypothesized that the broken rice with different size exhibit distinct features thereby classifying them according to size will accommodate their respective end use. Particle size of the rice flour exhibits differences in their functionality and gelling properties thereby affecting the rice noodle quality. HMT and OPT exhibit similar changes in the starch; therefore, OPT starch may also be utilized in the rice noodle production. Formation of RS during HMT and OPT might be helpful in enhancement of RS content in rice noodles.

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