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MiniReview
Cracker “Keropok”: A review on factors influencing expansion

Taewee, T. K.

Department of Food Science and Nutrition, Faculty of Science and Technology, Prince of Songkla University, Pattani campus, Pattani, 94000 THAILAND

Abstract: Cracker “keropok” is a popular snack food product in ASEAN community which has high potential economical impact. This review has accomplished two main objectives. Firstly it summarizes the key results from prior work, and enables the reader to easily find the key references on starch hydrothermal behavior related to keropok manufacturing, among other key issues discussed. Secondly, it identifies several gaps in current knowledge that can be addressed by further research, to facilitate quality improvements and quality monitoring in future industry scale manufacturing processes.

Keywords: Fish cracker, keropok, expansion, starch, review

Introduction

Keropok is a dried crispy food product relatively popular in South-East Asian countries, and currently its manufacturing is mostly practiced in small scale. It seems to have market potential for growth. However, the quality of keropok manufactured in small scale seems not to be consistent. Also the transition from small manufacturers to larger scale manufacturing requires an engineering and scientific understanding of the raw material and processing options. This review consolidates knowledge of the effects of raw material characteristics and current processes’ conditions on product quality measures, as well as identifies gaps in knowledge for relevant research opportunities. In practice, cracker expansion is the only well-established quantitative characteristic of the final product that is known to strongly correlate with the taste preferences of a human panel. For tuning various options to optimize product quality, this current literature review must of necessity emphasize factors influencing expansion.

The current economic significance is shown by the multitude of small-scale keropok, especially fish cracker manufacturers in both Malaysia and Thailand. It can be estimated that in Southeast Asia there is significant growth potential in the market. There is recent anecdotal information that the capacity restriction has been highlighted by a Chinese request for supply which exceeded the available capacity. The main limitation is in the manufacturing technology and its capacity. There are, however, unsolved problems on attempting to scale up the production. In small scale operations, the quality of the product is known to fluctuate, while the cause of these fluctuations is not well understood; it appears to stem from raw material rather than processing conditions.

As for raw material selection, currently cassava and sago dominate as the starchy flour component. These are easily available to the producers, price competitive with other alternatives, and have been shown by research reviewed below to be most appropriate for keropok. To control the quality of starch raw material is, however, difficult due to lack of scientific/technical understanding and currently no cooperation between starch manufacturer and keropok producers has been established to clarify optimal starch characteristics for this use. Scientific/technical gaps exist especially in relating product quality and starch raw material characteristics. Fish or shrimp is commonly used as a protein source in keropok. This affects the quality of both the intermediate and the final products, which will also be discussed.

For health and nutritional purposes, keropok provides a dry easily stored and conserved form of nutrition with protein and starch, while vitamin and micronutrient additions could also be considered.

In this review, the current manufacturing process is outlined in its main unit operations, that a scaled up process likely would need to replicate. The influence of the raw material and preprocessing conditions for the quality characteristics of the intermediate product are reviewed. The dependence of final product quality, on both of final processing and the intermediate product characteristics as well as raw material choices, is reviewed. The knowledge gaps found, that are deemed essential research opportunities, are discussed.

Overview of current keropok manufacturing process and final product quality targets

Keropok is a traditional cracker product in Southeast Asian countries. It is called “kaogrieb” in Thailand, “keropok” in Malaysia and “krupuk”, “kerupuk” or “kroepoek” in Indonesia and “bánh

*Corresponding author.
Email: *taewee.tongdang@gmail.com*
Tel: +66 (0)73312160; Fax: +66 (0)73335130

phồng tôm" in Vietnam. In Malaysia, fish cracker is consumed as fresh keropok (Keropok Lekor) and puffed keropok (Keropok Keping). This is similar to the three southern border provinces of neighboring Thailand, which have more than 200 small scale producers. Also in the states of Kelantan, Terengganu and some parts of Pahang Malaysia, there are more than 100 small scale producers of this product. This indicates the importance of keropok to these communities.

Ingredients for making keropok are starch or flour, seasoning (pepper, garlic, salt, sugar and monosodium glutamate); and the protein ingredient that gives its distinction to the name of the cracker. For example, the varieties of keropok cracker include fish cracker, shrimp or prawn cracker, and pumpkin cracker. Starch or flour is a principal ingredient for making keropok, and technically the protein component can be altogether skipped and a less tasty puffed cracker created.

In keropok making process, starch is mixed with ground fish and other ingredients and then kneaded to obtain dough. The dough (in the typical manual process) is formed to a cylindrical shape (with diameter around 5 to 10 cm) and then cooked by boiling or steaming. The cooked dough is cooled and cut to thin slices (thickness can be around 3 mm) and then dried, either in sunlight or with a hot air dryer. The dried cracker obtained is considered a half finished product or intermediate product – this is typically fried in hot oil to obtain the edible puffed cracker. The linear expansion is of the order 80%, i.e. all length measures would be multiplied by 1.8, and the final crispy product with foamed structure is about 5 mm thick and can be the size of a hand. The high porosity does not enhance imbibition or flow, instead the pores are like bubbles, which is why the structure is described as foamed or cellular. In this review, references to numeric values of expansion always indicate linear expansion and assume isotropic expansion; the factor of linear expansion would be raised to third power for volumetric expansion. Some standards for the quality of keropok have been issued in Thailand and in Malaysia. According to the Thai industrial product standard the moisture content of half finished cracker should not exceed 12% and for puffed cracker the corresponding limit is 3% (Thai Industrial Standards, 1987). Although this kind of product has been known in Southeast Asia for many decades or perhaps for centuries and some research on it has been published, in commercial scale there are still problems. Inconsistent cracker quality, especially due to poor expansion, has been generally found. Good quality of cracker requires sufficient expansion from puffing, crispness, as well as low moisture content and low oil absorption. Similar to other kinds of starch-based snack, crispness is considered an important attribute of puffed cracker. Crispness and consumer's preference were reported to be ranked in the same order and it is important in food acceptability (Katz and Labuza, 1981). For ideal crispness the cracker should have linear expansion higher than 77% (Siaw *et al*., 1985).

Based on the above information, a key quality criterion is crispness, which (rank) correlates with the measurable characteristic of expansion. While undoubtedly the sensory perception of taste is also a key quality factor, it does not constitute a mainly engineering and scientific problem in terms of well-defined measurable quantities. For these reasons, the remainder of this review emphasizes expansion and factors affecting it.

Factors affecting keropok expansion

Raw material characteristics

Clearly the final product quality, especially its expansion, will be affected by the raw materials. As the final puffed product can comprise only starchy flour (with moisture), the properties of starch and how they are manipulated and modified by the processing are of key importance. Due to an extensive history of starch research, important raw material characteristics and at least a partial interpretation of the effects of the processing steps are available. When focusing on a single type of protein component such as fish, and a narrow range of compositions (mixing ratios) perhaps dictated by consumer taste, the variations in quality are probably primarily controlled by starch quality and its changes during the processing, and the interference of the other components with these changes. For these reasons, this literature review is heavily weighted on the starch component.

Starch type and its properties

Starch is the main ingredient in cracker or keropok, hence it plays an important role to cracker quality. The common knowledge about starch components and structure is generally available (Hizukuri *et al*., 1989; Morrison and Karkalas, 1990). The content and molecular structure of both starch components depends on the plant source and the conditions of growth or environment, storage after harvest, and also on the fractionation and purification method. These have an effect on the functional properties, and could affect product quality. The type of flour or starch used for making cracker is well known to affect cracker quality.

In research studies, different kinds of starch/flour have been tried and tested for making cracker, for example cassava, rice or sago starches, as shown in Table1. From those studies, the emerging consensus appears to be that sago and cassava provide better expansion of cracker than the other starches. However, keropok made from cassava starch has a higher expansion that one made from sago starch (Mohamed *et al*., 1989; Tongdang *et al*., 2008). When other kinds of starch were mixed with cassava starch, keropok expansion was observed to decrease (Mohamed *et al*., 1989; Tongdang *et al*., 2008; Saeleaw and Schleining, 2010). Some details of this evidence are reviewed below.

Mixtures in various ratios of cassava and sago starches have been used for cracker making and compared to cassava cracker (Tongdang *et al*., 2008). In these studies, cassava starch provided higher expansion of cracker than the mixed starches. Increase of sago starch fraction in the mixture results in a decrease of expansion. Sago has a higher amylose content, it promotes retrogradation, resulting in a stronger gel, thus resisting expansion. A similar result was obtained when cassava is replaced by mung bean starch (Mohamed *et al*., 1989). Recently, Saeleaw and Schleining (2010) used mixtures of four types of flour (cassava, waxy rice, non waxy rice and wheat flour) for making cracker, and again a higher fraction of cassava showed higher expansion. Pregelatinized starch has been used to make cracker (Yu and Low, 1992) in order to reduce the cooking time of keropok dough. This naturally affected the linear expansion, and it was found that cracker could be more easily cooked than on using native starch.

In commercial cracker manufacturing, flour which is commonly available is used, instead of using purified starch which could be extracted from the flour at some expense. However some types of flour from natural plants can be practically considered as starch, without such purification. Starch should contain only amylose and amylopectin, but small amounts of other components are acceptable. Cassava and sago starches are commonly used for cracker making in commercial scale due to these providing a good expansion of the final product as discussed above. Although in Thailand both cassava and rice flour are available widely and in large quantities, only cassava is commonly used for keropok cracker, while rice is preferred for making another kind of cracker, called "arare" or "senbie". Rice flour has a higher content of protein and lipid than cassava. Lipids have a strong effect on starch properties and affect product expansion (Chinnaswamy and Hanna, 1988). To remove those components and obtain rice starch is costly, and not a viable option in keropok manufacture. Cassava is preferred in Thailand while sago is more popular in Malaysia and Indonesia. Properties of these two starches have been reported by many research groups (Ahmad and Williams, 1998; Defloor *et al*., 1998; Ahmad *et al*., 1999; Sriroth *et al*., 1999; Hoover, 2001, Moorthy, 2002; Singh *et al*., 2003; Aryee *et al*., 2005; Singhal *et al*., 2008).

Cassava starch is obtained from the root of cassava plant (*Manihot esculenta Crantz*). Normally manufactured cassava flour is almost pure starch, and can be considered starch rather than just starchy flour. According to Thai Industrial Standards no. 271-2521 (Thai Industrial Standard Institute, 1978) cassava starch should contain not more than 0.3% of protein 0.15% of ash and 0.15% of fiber. Cassava flour in its commonly commercially available form satisfies these requirements and is considered starch flour. Sago starch is obtained from the trunk of sago palm. Malaysia is one of the top three countries in production of sago, and sago is the main carbohydrate source. Similar to cassava starch, protein and lipid contents of sago starch are also very low. Amylose content and granule size of sago starch are, however, higher and bigger than those of cassava starch, respectively. The genetic variation and environment of growth, stage of harvesting, as well as starch producing process cause starch quality variations.

Clearly, in any natural plant starch there will be quality variations from batch to batch, and the range of these variations is not yet well characterized. The natural approach then is to determine from laboratory studies the effects of quantified quality variations, for example from starch mixtures, and in an industrial process implement quality controls that help refine the gained understanding to useful industry practices. The individual studies provide fixed observation points, and by these an expectation of the ranges to be covered by quality control measurements.

In general, different types of starch have different compositions and functional properties, in more dramatic ways than expected for variation within an individual starch type. Starch composition has been shown to influence cracker expansion. Protein in flour seems to inhibit cracker expansion. Expansion of keropok decreased with choice of flour from cassava to sago to wheat starch/flour, the explanation offered is, that wheat starch/flour has higher protein content than those of cassava and sago (Mohamed *et al*., 1989; Yu, 1991a). When cassava starch was mixed with mung bean starch, the cracker expansion decreased as mung bean content increased. The protein in flour/starch seemed to reduce its hot paste viscosity, in comparisons between mixture flours that had similar ratios of amylose and amylopectin (Mohamed *et al*., 1989). In this work, no explanation was offered as to why the expansion of crackers made from cassava was higher than of those made from sago starch.

Amylose-amylopectin ratio in starch has a strong effect on expansion of starch based snack (Matz, 1984; Wang, 1997). Keropok made from various flours, which had different amylose-amylopectin ratio, were compared in their expansion (Mohamed *et al*., 1989). It was found that linear expansion of cracker correlated positively to the amylopectin content in flour. They give this fitted equation, which must be incorrect since it gives negative upper bounds on positive y: (21y$\leq$ 0.35x-162, r^2 = 0.99). (x= % amylopectin, y = linear expansion). These authors suggested that keropok product could beneficially be made from "high amylopectin flour", which would improve stability to retrogradation, and provide low resistance to shear and high cold-paste viscosity.

As mentioned above, cassava and sago are both widely used for making keropok, due to both availability and their positive effect on product expansion (Yu *et al*., 1991; Choew *et al*., 2004; Tongdang *et al*., 2008). However, cassava starch gives higher expansion than sago (Yu *et al*., 1991; Choew *et al*., 2004; Tongdang *et al*., 2008). These two starches are similar in terms of containing very low protein, lipid and ash, but their functional properties are affected by the granule sizes, amylose contents, etc. – so their gelatinization temperatures, pasting and retrogradation properties are different. Sago starch has higher amylose content than cassava starch resulting in stronger cracker gel due to higher retrogradation.

Protein source

Fish and shrimp are the main protein sources for making keropok. Both types of keropok are commercially available. Fish keropok is cheaper than shrimp keropok as raw shrimp is more expansive. Literature does not provide any research work the role of shrimp meat on cracker expansion. Most of the reported research has been done on fish keropok. Fish keropok typically contains by weight less fish meat than flour, but the content may be made as high as 50% of total ingredient weight. Fish is deboned and mixed with seasoning such as salt, sugar, and monosodium glutamate. The options for fish meat in fish cracker have been considered by fish type, quality, and quantity.

Fish type and its content

Marine fish is more common than fresh water fish. Different kinds of fish as shown in Table 1, have been experimentally used for making fish keropok. While in commercial production, fish type choices depends on availability, cost and quality of final product obtained. Although there are many kinds of fish that have been used to make cracker, no report compares fish types or how the choice affects cracker expansion. Fish protein hydrolysate (Yu and Tan, 1990) and surimi (Huda *et al*., 2000, 2001) in dried powder form have also been used for fish cracker formulation (in laboratory studies). Washed water protein from fish ball processing is also used for fish cracker formulation by Yu *et al*. (1994).

Table 1. Types of starch (or flour) and fish used for making keropok

Type of Starch or fish	References
Starch/ flour	
Sago	Mohamed *et al*.(1989); Cheow and Yu (1997); Cheow *et al*. (2004); Tongdang *et al*. (2008)
Cassava	Mohamed *et al*. (1989); Cheow *et al*. (1999); Kyaw *et al*. (2001a,b); Huda *et al*. (2001); King (2002); Cheow *et al*. (2004); Tongdang *et al*.(2008); Huda *et al*.(2009); Saeleaw and Schleing (2010, 2011)
Rice flour	Mohamed *et al*. (1989); Yu (1993)
Corn flour	Mohamed *et al*.(1989)
Wheat	Cheow *et al*. (2004)
Pregelatinised starch	Yu and Low (1992)
Mixed starches/flour	Mohamed *et al*. (1989); Tongdang *et al*. (2008); Saeleaw and Schleining (2010)
Fish	
Sardine (*Clupea leiogaster*)	Yu (1991a)
Jewfish (*Johnius soldado*)	Kyaw *et al*. (1999); Kyaw *et al*. (2001a)
Big-eye (*Brachydeuterus auritus*)	King (2002)
Snapper (*Lutjanus* spp), Yellow pike conger (*Ophiocephalus micropeltis*), Feather back (*Natopterus chilata*)	Peranginangin *et al*. (1997)
Dory fish (*Pangasius hypophthalmus*)	Huda *et al*. (2009)
Fish protein hydrolysate	Yu and Tan (1990)
Powered surimi	Huda *et al*. (2000, 2001)

Fish content or fish: starch ratio influences the degree of linear expansion of fish crackers (Yu, 1991a,b; King, 2002; Huda *et al*., 2009). The linear expansion of fried cracker has been found to decrease as fish content increases (Yu, 1991b; Yu *et al*., 1994; Paranginangin *et al*., 1997; Cheow *et al*., 1999; Huda *et al*., 2001; Kyaw *et al*., 2001b). At a high fraction of fish meat in cracker, i.e. 700-800 g/kg, the proteins form a continuous gel network with starch appearing as filler, resulting in a reduction of cracker expansion (Cheow *et al*., 1999). Keropok gel without fish or containing less than 10% fish when heated by steaming for 100 min was not fully gelatinized, while those with at least 15% fish meat showed full gelatinization (Kyaw *et al*., 2001b). Cheow *et* *al*. (1999) found that cracker dough gel containing 200-300 g/kg fish (fish-starch mixture) and without added salt, was not fully gelatinized. Cheow and Yu (1997) have shown that fish content affects the onset and peak gelatinization temperatures of fish-starch mixtures of cracker by raising those temperatures, while conclusion temperature is not affected. Fish quality; there is no information on how fish quality affects cracker expansion. It has been mentioned by Cheow *et al*. (1999) in which poor fish caused a decrease in cracker expansion.

Seasoning

Seasonings used in keropok making include salt (sodium chloride), sugar, and monosodium glutamate. Some herbs, for example black pepper and garlic may be added. The information how these seasonings affect keropok expansion is limited. However, there are a few reports on effects of seasoning (salt, sugar and mono sodium glutamate) on gelatinization and gel properties of fish- starch system with> 61% water content (Cheow and Yu, 1997; Cheow *et al*., 1999). Salt is normally added around 2% of total keropok ingredients (with their moisture, but not counting in added water or ice). It plays an important role on fish protein solubility and gelation. Adding salt (at least 20 g/kg) helps fish-starch gel to be fully gelatinized, especially in the case of low fish content (200-300 g/kg) in keropok, and hence improves cracker expansion. The salt helps protein to disperse in to starch (Cheow *et al*., 1999). Salt also affects starch gelatinization. At the same moisture content (61%) starch-fish protein mixed paste with 2% salt, had higher gelatinization temperature than that without salt treatment by 4-5°C (Cheow and Yu, 1997). The same salt content affected viscoelastic properties of fish-starch gel by increasing storage modulus G' by about 150% (Cheow *et al*., 1999). Jomduang and Mohamed (1994) reported that salt helped improve puffed product quality of a traditional Thai glutinous rice-based puffed snack. Volumetric expansion of extruded starch increased from 13 to 16.9 as salt content increased from 0 to 1 g per 100 g (Chinnaswamy and Hanna, 1998). Sugar (1%) and MSG (0.4%) has little effect on viscoelastic property (Cheow and Yu, 1997) and less effect to gelatinization temperature of fish-starch mixtures than salt (Cheow *et al*., 1999).

Preprocessing and intermediate product

To obtain intermediate or half product, the pre-processing comprises ingredient mixing, kneading, cooking, cooling, slicing, and drying. The half product is actually a dried gel, with about 12% moisture content. It needs to be puffed to obtain the final product for human consumption, and the intermediate product is convenient for storage and transport due to its reasonable density and good preservation at room temperature. It also provides an opportunity to determine intermediate quality characteristics that can be related to the final product quality. Such characteristics could be important for determining the value per weight, or for selecting options for final processing – while currently not practiced, it might even be possible to mix different batches of the intermediate product to reach uniformly sufficient final quality. Further, the immediate effects of the pre-processing are possibly most clearly observable in the intermediate product, and its characteristics may provide feedback for the optimization – or just for maintaining steady operation – of the preprocessing stage. For these reasons the quantitative characteristics of the intermediate product are discussed at some length.

Mixing

Mixing is a crucial step that helps cracker ingredients (fish, starch, water/ice and seasoning) to be well mixed throughout, and hence a good quality uniform product can be obtained. The important choices when using a given mixer are 1) sequence of adding ingredients for mixing and 2) mixing time and shear. There is limited information on the effects of these factors on fish cracker expansion. So far, we know of only one report (Cheow *et al*., 1999) that discusses the importance of sequencing the addition of ingredients during mixing cracker dough. Salt and other seasonings should be added to the mix with fish meat, and starch is added later. This has been consistently practiced in commercial and household scale production. If salt is added after fish and starch have been mixed, the fish protein is found to aggregate and a less uniform dispersion of fish protein in the starch system results in; this can reduce cracker expansion (Cheow *et al*., 1999). The reason is probably the salting in effect, in which salt helps protein to solubilise and disperse. The same work also reported that without salt or with too low salt concentrations, up to 10 g salt/kg, lumps of fish protein were seen under microscope, and a decrease in cracker expansion was observed (along with the protein aggregates).

Mixing time is also important to cracker expansion, but only preliminary work has been reported by Cheow *et al*. (2004); mixing time affected cracker expansion but this work did not provide any quantitative information. Mixing and cooking without water are impossible. In the mixing step ice is added to mix with other ingredients. Ice is used instead of water in order to prevent a temperature rise during mixing, which would cause weakening of the fish protein gel, and might affect cracker expansion. Again the information available is very limited.

Cooking

The keropok making process involves hydrothermal heating by steaming or boiling in water. The purpose of this step is to cook keropok dough, and the starch in dough is gelatinized and forms a gel. The heating method for cooking is currently always steaming or boiling, while other potential alternatives could be worth research studies. The boiling method allows – in principle – full gelatinization of the keropok as starch in the dough can take up water from environment. This helps shorten the cooking time. The steaming method also gelatinizes starch; however, complete gelatinization may or may not be achieved. This depends on the temperature and steaming time (Kyaw *et al*., 1999; Tongdang *et al*., 2008), as well as water and starch contents in dough (Kyaw *et al*., 2001b). The effect of steaming time on starch gelatinization has been observed (Yu *et al*, 1999). Keropok dough (1:1 fresh fish to cassava starch; 30% water) was steamed at 100°C and atmospheric pressure for 1 hr. Samples were taken every 10 min. Fully gelatinized samples were found after steaming for 20 min while the temperature in the center of keropok rod was 92°C. In this study a 1-1 ratio of fish and starch was formulated, while 30% water of starch+wet fish weight was supplied. (This means in 100 g of mixture there are about 35 g fish, 35 g starch and 30 g of added water, and also water from fresh fish (about >18 g). Therefore starch could be cooked easily, in the presence of excess water. Wheat starch keropok had poor expansion compared to sago and cassava if steamed at 100°C, but if steamed at 120°C the quality was similar to that made from sago and cassava (Kyaw *et al*., 1999; Noranizan *et al*., 2010).

Degree of starch gelatinization (DG) in cracker dough affects cracker expansion (Tongdang *et al*., 2008). Cracker was produced from 40% of mixtures of cassava and sago starches and 60% water, with steaming times of 25-120 min. The DG of cracker dough was in the range 55-65% when steamed for 25-45 min. DG was at least 80% if steamed 60-120 min. It was found that cracker expansion increased as DG increased. However, the maximum expansion was found at 60 min steaming time, and decreased with steaming times longer than this due to starch fragmentation. The extent of starch degradation depends on both heating temperature and duration. Treating starch with excessively long heating period or high temperature affects its structure by making it more disordered and degraded, resulting in a less strong cracker gel. The expansion of cassava cracker steamed at 100°C more than 60 min (75-120 min) decreased due to fragmentation of starch as revealed by increased water solubility index and decreased water absorption index (Tongdang *et al*., 2008) or by gel strength decrease (Kyaw *et al*., 1999). A strong gel may resist bubble formation, while a weak gel can not. Frying in hot oil allows water to vaporize rapidly in starch gel, and the vapor bubbles are formed and trapped in cracker. The collapse of air cells, or their merging, due to loss of cell wall strength, would match the observed loss of air cell density by number count (Tongdang *et al*., 2008). The cooking temperature also affects starch degradation. Gel strength of cassava cracker gel decreased and expansion increased with cooking at temperatures of 100, 108, 115 and 121°C for 30 min; while reversed results were obtained for wheat starch cracker (Kyaw *et al*., 2001a).

During the gelatinization process, there are irreversible changes in the starch granule (breaking of hydrogen bonds, water uptake, swelling of granule, melting of crystallites or double helices, birefringence loss, and solubilization). The starch granules are enriched in amylopectin, because the linear amylose diffuses out of the swollen granules (Hermansson and Svegmark, 1996). Swelling power of granules has been reported to relate to cracker expansion. This property greatly depends on the type of starch and its structure arrangement (Tester and Morrison, 1990). Cheow *et al*. (2004) have compared the swelling power and solubility of sago, cassava and wheat starches and found that these decrease from sago to cassava to wheat; they suggest this is due to effects of protein and lipid in starch. It is known from other studies that protein and lipid inhibit the swelling power of starch (Leach *et al*., 1959; Tester and Morrison, 1990; Pomeranze, 1991). The ratio of amylose and amylopectin also affects the swelling power and solubility. It has been suggested that amylopectin plays a key role on swelling of starch granules, while amylose acts as a swelling inhibitor and diluent (Leach *et al*., 1959). However, in the study (Cheow *et al*., 2004) cassava had the highest amylopectin fraction followed by wheat and sago respectively; not matching the rank order of swelling power observed. Granule size of the initial native starch does affect swelling of the granules (Tongdang *et al*., 2008); the swelling power at the temperatures of 75, 85 and 95°C, of sago starch was higher that that of cassava starch; and that is apparently due to sago having a larger granule size than cassava (33.8 μm vs 12.9 μm).

Fish crackers made of different starches were compared in terms of the swollen starch granules in cracker gel, and cracker expansion after frying. The size of swollen granules in the cracker gel decreased from sago to cassava to wheat while cracker expansion decreased from cassava to sago to wheat (Cheow *et al*., 2004). The granule size of native sago starch at average is bigger than that of cassava starch, and is followed by wheat starch; this can affect water uptake during heating and hence swelling of the granules. Size of granule in cracker gel of cassava starch was smaller than that of sago, but cassava cracker expands more than sago. The reason for this could be related to other properties of starch, i.e. gelatinization and retrogradation, and consequent effects (Tongdang *et al*., 2008; Noranizan *et al*., 2010).

Interaction between amylose and lipid during gelatinization also affects water uptake of granules during heating process, affecting the eventual size of swollen granules. Cheow *et al*. (2004) found that at the temperature of 100°C, swelling power of cassava and sago starches are very similar, around 90% while that of wheat starch is below 20%. At the temperature of 120°C it increases to similar level with cassava and sago at 100°C (Noranizan *et al*., 2010). Wheat contains a larger fraction of lipid and the amylose-lipid complexes are formed during heating. This complex prevents wheat starch granules from swelling at temperatures around 100°C, but the complex is destroyed at higher temperatures allowing the granules to swell, with amylose leaching out from the erupted granules. No information on expansion of keropok made of wheat starch was reported in this study. However, it is possible that at the same frying temperature, wheat flour keropok steamed at 100°C (called A-keropok), would have less expansion than keropok steamed at 120°C (called B-keropok). This could due to amylose- lipid complex of B-keropok has been melted during steaming, and hence the gel is easy to puff and has higher expansion that A-keropok.

Amylose and amylopectin leaching that occurred during starch gelatinization has been also reported to relate to cracker expansion (Kyaw *et al*., 2001a; Cheow *et al*., 2004; Noranizan *et al*., 2010). As the gelatinization temperature varies according to starch type, the gelatinization temperature range of each starch can be different. Hence the same heating temperature and time will have different effects on swelling, solubility and amylose leaching of each type of starch. Noranizan *et al*. (2010) have investigated amylose leaching of wheat, sago cassava and potato starches at different temperatures and heating durations. They have found that amylose leaching pattern is similar to solubility pattern; as temperature and heating time increase, also the amylose leaching increases. Heating at 100°C for 1 hr, 66% wheat amylose leaching was obtained while sago, cassava and potato starches did retain over 85% of their original amylose contents. The cassava, sago and potato starches (5 g in 180 g water) solubilize completely when heated at 120°C for 1 hr, while it takes 2 hrs for wheat starch, at this temperature, and all amylose of all starches has been leached out. They found that good expansion of cracker is obtained when the ratio of leached amylose to leached amylopectin is 0.25-0.5.

Reducing agent, i.e. ascorbic acid has been reported to affect expansion of cassava extrudate. Sriburi and Hill (2000) have demonstrated that cassava starch had been extruded with various concentration ascorbic acid included, and in a pellets form. They have found that the expansion of fried pellets increased with increasing ascorbic acid concentration. Starch degradation occurred, as shown by decreasing in their viscosity and increasing in water solubility index. Ascorbic acid had great effect on starch depolymerisation, even at only 0.1% addition it still causes significant change. Similar results were obtained with autoclaving cassava starch and ascorbic acid; the depolymerization of starch increased with concentration of ascorbic acid (Sriburi *et al*., 1999).

Cooling

In the cracker making process, after cooking, cracker gel is left to cool and stored in an ice box or refrigerator, to obtain harder gel and to enable easy slicing. Retrogradation of cooked starch will occur at this step of the process. The term "retrogradation" is used to describe the changes that occur upon cooling and storage of gelatinized starch. It refers to the extensive re-association of the polymers of gelatinized starch (Atwell *et al*., 1988), causing effects such as precipitation, gelation and changes in consistency and opacity (Hermansson and Svegmark, 1996). It involves the re-association of amylose molecules to form the double helical chain segments and helix-helix aggregation; this is then followed by a slow crystallization of the short chains of amylopectin (Biliaderis, 1992). The crystallization of amylopectin is responsible for the long - term changes in the firmness of starch gels on storage (Ring *et al*., 1987).

Retrogradation of starch gel depends on starch type and composition, storage temperature and time. Cassava has lower amylose content than sago starch; and if cracker dough is heated at the same temperature for the same period of time, cracker gel of the former starch will be softer than that of sago starch and the softer gel is easier to melt and puff upon frying. Hence cracker made from cassava starch has higher expansion than that made from sago starch (Mohamed *et al*., 1989; Yu, 1991a; Choew *et al*., 2004; Tongdang *et al*., 2008). Storing cracker gel after cooking in ice box or refrigerator is common practice. In this stage retrogradation leads to harder cracker gel. After drying sliced cracker gel, dried cracker is obtained as half product; it is ready for packaging and distribution, and storage at room temperature. In this stage starch retrogradation in dried cracker (dried gel) may also occur, and this may affect cracker expansion. However, we are not aware of any report on effects of storage conditions on cracker gel and dried cracker, or its expansion. It would then seem a reasonable research topic to assess the magnitude of effects on expansion from comparing some extremes in the cooling, drying and storage times – whether these can cause large variations in final product quality is currently unknown, but appears possible.

Drying

The purpose of this step is to reduce moisture content of cracker gel. The optimal moisture content of the intermediate product, relative to storage effects and final product quality, has not been reported. The standards impose an upper limit on 12% moisture content (Thai Industrial Standard, 1987), possibly anticipating microbial spoilage at higher moistures. On the other hand, for expansion due to vapor formation, and for softness and deformability of the solid phase, it is necessary to have some minimum level of moisture in the final puffing – so a minimum limit could be determined based on these requirements for the moisture in the intermediate product. Maximum linear expansion was obtained from dried cracker which had 15% moisture content (Nair *et al*., 1996).

Predictive models of drying rate in a tray drier with controlled hot air temperature and circulation have been developed (Lertworasirikul, 2008; Lertworasirikul and Tipsuwan, 2008). However, in commonplace drying under sun, many factors such as wind, humidity of air, temperature, and the intensity of heating by sunlight, would likely make a predictive model practically impossible. In such conditions, and also in an industrial better controlled process, feedback measurements would be more valuable than predictive models. It is likely that in home scale manufacture, sensory perception (such as biting a chip to feel its hardness, observation of color or changes of shape) is commonly used. A multitude of relevant potentially useful measurements can be proposed for consideration. Infrared non-contact moisture sensors could be useful, and a hardness measurement would also be quick; while more accurate determinations using heating and evaporation will necessarily be slower.

For an industrial operation the ideal combination might be a robust hardness measurement for rapid feedback, with correlation to a slow but accurate moisture determination for calibration at suitable intervals. Electrical conductivity may be too easily perturbed by composition and salt content, while NMR (Nuclear Magnetic Resonance) based observations are likely prohibitively costly for widespread use. Overall, a feedback observation of moisture content seems desirable, while there clearly is a gap in our knowledge of the final processability and quality effects of the moisture in the intermediate product.

Characteristic of final product

The final product is puffed keropok ready for human consumption. In the process, deep fat frying in hot oil is applied in order to puff the intermediate product into a cracker. This method is traditional and has been in use for a long time. From olden days until now, frying is still a popular method in cracker production, both in household and commercial scale. Other puffing methods should be considered and developed for cracker making. A puffing machine has been developed and used for fish cracker puffing process; and a higher expansion than with the frying method was obtained (Kok *et al*., 2004). Not using oil, this method provides a possibly healthier product. We suggest that the puffing step in cracker making process, needs to be improved. Oil-free processes should be considered, not only in the laboratory but for commercial scale. Microwave heating is also a potential method for cracker puffing.

The expansion ability of cracker is determined as 'linear expansion' (Yu *et al*., 1981). Typically 3-5 lines are ruled across cracker slice, and each line is measured before and after puffing. The calculation is made as:

Percentage linear expansion = (Length after puffing – Length before puffing) x 100/ (Length before puffing)

The replication number should be considered as high variation of expanded product could be obtained. 20-25 slice samples have been used to determine linear expansion for each treatment (Yu *et al*., 1981; Kyaw *et al*., 2001a; Cheow, *et al*., 2004). An acceptable quality puffed cracker should have high expansion and crispness, as well as low oil uptake. Frying process is a crucial step to obtain those characteristics. Although the main purpose of frying in hot oil is to puff the cracker, other changes also occur in this step. There are, including heat and mass transfer, water evaporation and formation of the cellular porous structure (Bhat and Bhattacharya, 2001) loss of moisture content (Krokida *et al*., 2000; Saeleaw and Schleining, 2011), protein denaturation, starch gelatinization and color development (Maneerote *et al*., 2009).

Although frying is a very important step in cracker making, surprisingly, in the literature reviewed here most research has paid attention on ingredients and cooking effects on the intermediate product; but there is little reported work on cracker frying. However, in cracker preparation, the published reports have documented temperatures and durations of frying; 200°C for 15 s (Mohamed *et al*., 1989; Yu, 1991a; Cheow *et al*., 1999; Kyaw *et al*., 2001a; Cheow *et al*., 2004); 180-200°C for 1-2 min (Yu and Low, 1992); 150°C for 3 min (Huda *et al*., 2001); 190°C for 30s (Tongdang *et al*., 2008); 180-200°C for 1 min (Huda *et al*., 2009); 160°C for 10s (Saeleaw and Schleining, 2010). Clearly there is a large range of parameters that can be applied, and currently no clarity on the quality effects of these choices.

The bulk density of cracker, which can be an indicator of puffing, has also been used for cracker expansion determination using sesame seeds displacement (Sahin and Sumnu, 2006) and the measurement results are expressed as cracker density, i.e. mass per volume (ρ = m/v). This method is acceptable to determine expansion of puffed cereal grain. However, there is only one report so far (Saeleaw and Schleining, 2011) of using this method to monitor the puffing ability of cracker. From this work, bulk density has a significant (99% confident) negative correlation to linear expansion (r^2 = -0.8422). Some factors, frying time, oil temperature and moisture content of half product have been reported to affect cracker expansion, and the frying was performed at 200°C for 40 s, with 15% mc of dry cracker (Nair *et al*., 1996). The effects of temperature and duration of frying on cracker expansion, bulk density, moisture content and oil absorption have later been reported by Saeleaw and Schleining (2011). Comparison of cracker frying temperatures (140, 150 and 160°C) and time (10, 20 and 30 s) was reported in this work. It was found that with increasing frying time and temperature, the linear expansion significantly increased, with corresponding increase of bulk (lower density). The frying time has a larger effect at lower frying temperatures. Note that the temperatures reported by others extended up to 200°C, so this study focused on a comparatively narrow temperature range.

Air cell formation during frying relates to expansion, as the higher the degree of the expansion of the cassava crackers, the more air cells will form (Huda *et al*., 2009; Saeleaw and Schleining, 2011). Cracker frying at a higher temperature (160°C) induced a larger number of small sized air cells than frying at a lower temperature,140°C (Saeleaw and Schleining, 2011). Once cracker contacts the hot oil, the moisture is evaporated and forms pores in the cracker (McDonough *et al*., 1993; Ngdi *et al*., 2009; Saeleaw and Schleinig, 2011). Air cell or pore distribution in cracker influences texture, especially crispness and hardness of this product (Ngdi *et al*., 2009). Just like in other expanded low moisture product, expansion is related to crispness; and has impact on acceptability to consumer.

Suggestions for future research

Quality of raw flour or starch is important for cracker expansion. As small scale producers normally buy flour materials from a dealer, there is no contact or collaboration between the starch manufacturer and the keropok producers. The relation between starch raw material properties and intermediate and final product quality, produced from each batch of starch could help the cracker producer to control the final product quality. The standard quality of flour or starch for keropok making could be experimentally determined.

This review found practically no information on fish type and quality effects on cracker quality. This is still open to research for supporting keropok production. If there is no fresh fish available (i.e. in monsoon season) it may possible to add dried fish which is available all year round. Gelling ability of dried fish will be different from fresh fish as drying affects the fish proteins. Research on these factors, type and pre-processing of the fish, could fill a relevant gap in knowledge.

No quantitative information has been found on the final quality effects of starch retrogradation during cooling and storage of the intermediate product, or any study on the trends caused by storage time. The storage time may also cause degradation, or diffusion and redistribution, of the fish (or shrimp etc.) proteins in the cracker.

The effects of dimensions on the diffusion of heat and moisture or vapor have not been reported. Clearly, during the preprocessing the core of a large diameter dough cylinder will lag behind the surface upon heating, while a small diameter cylinder will experience more uniform cooking and hence drying. One could envision cooking spaghetti-like dough, and compressing it to desired shape once gelled, before drying, if core-to-surface non-uniformity is an issue.

The expansion could possibly be controlled to some extent, as opposed to the current practice in which expansion happens uncontrollably. For example, heating under pressure and then releasing the pressure by a controlled change of volume, would provide such controlled expansion. An entirely different approach would be to create a different pore structure, by 'puffing' a fibrous pad where the void space between the fibers dominates in determining the final bulk. The bulking of the individual fibers would only ensure that the pad expands to the limits provided mechanically, for example by metallic porous surfaces that could be heated. Whether such fibrous product would provide a pleasing texture similar to the current puffed product, with air cells as its pore volume, remains to be seen.

Sticking with the currently conventional uncontrolled expansion, there is a significant lack of knowledge on quality effects of the final process that converts the intermediate product to edible keropok. In particular, the temperature and duration of oil cooking has not been optimized, and alternative cooking processes have not been much studied. In an industrial process the intermediate product could be passed through a nip between hot metal rollers, it could be extruded, or it could be microwaved. For health conscious consumers oil-free processing could be attractive.

In nutritional aspects, keropok could be a particularly nutritious snack. It is not only providing carbohydrate and protein but also some micronutrients. However it might have limitations in vitamin content due to the high temperature of frying, but for mineral sources such as calcium that are stable at high temperature, creating enriched products would be possible. This would need more research to find appropriate calcium sources and content and also how those affect cracker quality; specifically for calcium, the plentiful calcium anchovies may provide an opportunity in Thailand.

Conclusion

Expansion is here considered the most important quality attribute of keropok product, which relates to acceptability by consumers. Many factors affect this quantitative characteristic with complicated interactions, and choices have to be made both in keropok ingredients and in processing. Based on current knowledge as reviewed above, several gaps have been identified that can be addressed by further research.

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