

# Asian Perspective on High-Moisture Extrusion

The-Thiri Maung<sup>1</sup> and Gi-Hyung Ryu<sup>2</sup>

Food and Feed Extrusion Research Center, Kongju National University, Yesan, Chungnam, South Korea

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## ABSTRACT

Asia has the fastest economic growth rate in the world, which has led to the development of its meat consumption culture. With a rapid increase in meat consumption across Asia, people are concerned about the negative impacts of meat consumption and production on the global environment, energy footprint, human health, social responsibility, and animal welfare. In response, a technology known as high-moisture extrusion cooking (HMEC) has been developed to produce high-moisture meat analogues (HMMA) that can mimic the fibrous and layered structure, texture, functional, and sensory properties of muscle meat. Both HMEC technology and HMMA have been well accepted and widely utilized in European countries, while they are still in the novice stage in Asian countries. This article briefly introduces meat consumption trends and different methods for the preparation of meat-based cuisines in three Asian countries, including South Korea, China, and Japan. A general explanation about the making of HMMA using HMEC technology is provided. The textural stability of HMMA after cooking, a comparison of HMMA with muscle meats, and future research needs for the Asian region are discussed.

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## Meat Consumption and Preparation of Meat-Based Cuisines in Asia

Asia is the largest and the most populated continent in the world, comprising 48 countries, including China, Taiwan, Japan, South Korea, North Korea, and Mongolia in Eastern Asia, as well as the countries of Southeastern, Central, Southern, and Western Asia (15). Asia has the fastest growing economy in the world and the largest economy as measured by both GDP (gross domestic product) nominal and PPP (purchasing power parity) (11).

In the past, meat consumption was lower in Asian countries than in Western countries due to their diverse cultures, religions, and staple foods. However, with globalization and economic growth, recent meat production and consumption have proliferated in Asian countries (21). Per capita meat consumption in the Asia Pacific region increased tremendously from 2.9 kg/person/year in 2013–2015 to 3.8 kg/person/year in 2016–2018 for beef and from 8.5 kg/person/year in 2013–2015 to 9.3 kg/person/year in 2016–2018 for poultry. Meat consumption in Asia is expected to continue to increase, and meat imports in Asia will dominate 56% of total global trade (23,24).

Because Asia comprises a wide range of cultures and environments, meat-based cuisines are also diverse among different cultures and regions across Asia (21). It is impossible to cover all of the meat-based cuisines found in Asian countries.

Thus, meat-based cuisines in three economically developed Asian countries, South Korea, China, and Japan, will be discussed.

South Korea has an ancient history of meat consumption (13). Beef, pork, and chicken are major meats used in Korean meat dishes. Beef is usually roasted, barbecued, grilled, used in soups, or stewed. Pork is consumed smoked, stewed, steamed, or boiled. Chicken is generally consumed roasted, braised with vegetables, or in soups (12,14,15,19). South Koreans enjoy eating meats, mostly in soups, and there are several different types of meat-based soups, namely *haejanggiuk* (pork spine soup), *galbitang* (rib soup), *yukgaejang* (spicy beef soup), *smagyetang* (ginseng chicken soup), *seolleongtang* (beef bone stock), *gam-jatang* (spicy pork soup with potatoes), *jeongol* (beef soup with tofu, mushroom, and vegetables), *sinsollo* (royal casserole with meatballs, mushrooms, and vegetables), as well as others (21).

Another major meat consuming Asian country is China. It has the largest population in the world, and its cultures are hugely diverse, leading to many different varieties of food in China. There are more than 100 different types of traditional Chinese meat-based cuisines (9,32). Common ways of cooking meats include stewing, stir-frying, braising with oil, and double steaming (32). Deep- or stir-frying is the most popular way of preparing meat among Chinese people (21).

Unlike South Korea and China, Japan's history of meat consumption is the shortest compared with other Asian countries (13). Originally, Japanese people preferred fish to chicken, beef, or pork. However, with increased Westernization of Japanese diets, meat-based cuisines became more popular. Currently, Japan consumes meats in the forms of deep-fried, grilled, steamed, stewed, stir-fried, and raw products (3).

Although meat consumption is expected to increase across Asia, awareness of consequences are rising globally as well. Because livestock production requires enormous amounts of energy and water, an increase in meat consumption will place a lot of stress on global crop and water resources (22). The "energy footprint" of meat production is enormous compared with other types of food. For example, the energy requirement for meat production is 75 times higher than that for corn. To produce 1 calorie of protein from soybean, corn, or wheat, only 2–3 calories of fossil fuel are needed, while 54 calories of fuel are required to produce 1 calorie of beef protein (7). Livestock production also contributes to the emissions of the three most important anthropogenic greenhouse gases, carbon dioxide, methane, and nitrous oxide, and is solely responsible for methane emissions (6).

The risk of animal disease outbreaks is also increasing globally (24). Furthermore, excessive consumption of meat results in excess intake of energy, leading to increased risk of cardiovascular diseases, diabetes, and certain cancers (27). In addition to environmental and health issues, there are ethical concerns related to animal welfare and religious practices. To help people reduce their meat consumption, meat substitutes or analogues have been developed. Meat analogues are 100% plant protein-

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<sup>1</sup> Department of Food Science and Technology, Food and Feed Extrusion Research Center, Kongju National University, Yesan, Chungnam 32439, South Korea. E-mail: [thiriyau08@gmail.com](mailto:thiriyau08@gmail.com); ORCID: 0000-0001-8577-4918.

<sup>2</sup> Corresponding author. Department of Food Science and Technology, Food and Feed Extrusion Research Center, Kongju National University, Yesan, Chungnam 32439, South Korea. Tel: +82-10-8880-0906; Fax: +82-41-850-8401; E-mail: [ghryu@kongju.ac.kr](mailto:ghryu@kongju.ac.kr); ORCID: 0000-0001-6704-4209.

based products with fibrous structures that can mimic meat in terms of functional, textural, and sensory properties (4).

Meat analogues typically have been manufactured using low-moisture extrusion with a moisture content below 35% and have a sponge-like texture that needs to be rehydrated before consumption (8). However, these low-moisture meat analogues (LMMA) cannot imitate the look and texture of animal meats. More recently, high-moisture extrusion cooking (HMEC) with a moisture content above 50% has become a promising technology for producing high-quality meat analogues from plant protein sources. Typically, raw meats contain a high moisture content ranging from 59 to 70% (31), and thus, high-moisture meat analogues produced by HMEC are comparable to muscle meats.

In the food industry, awareness of meat analogues among consumers has expanded dramatically recently, although they are a new product for consumers in many countries. European consumers show broad acceptance of meat analogues and HMEC (10,33). In the European food market, meat analogues are being marketed and consumed as convenience dishes in the form of vegetarian marinated strips, cubes, and nuggets and minced meat for sauces, fillings, burgers, goulash, salads, spreads, sausages, and many other applications (33). In contrast to European countries, acceptance and consumption of meat analogues in Asian countries is still in the early stages, which might be due



**Fig. 1.** Fibrous and layered structures of high-moisture meat analogues extruded from a mixture of soy protein isolate, wheat gluten, and corn starch (50:40:10) using high-moisture extrusion technology.

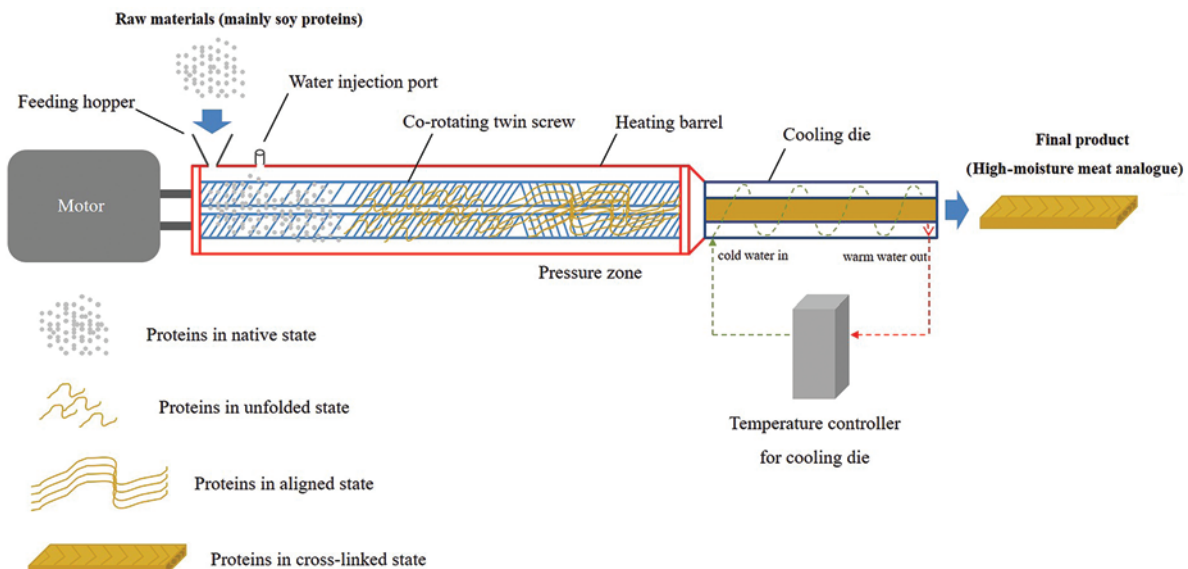
to lower consumption of meat originally in Asia than in Western regions of the world.

### HMEC and High-Moisture Meat Analogues

High-moisture extrusion, or HMEC, is an exceptionally promising technology for producing plant protein-based meat analogues. Formulations based on plant proteins, especially soybean and pea proteins, together with optimum process conditions, can create meat analogues with fibrous structures similar to muscle meats (16). In addition to soybean and pea, peanut, and mungbean proteins are also possible sources for successful texturization of meat analogues (30). HMMA usually contain high amounts of essential amino acids and lower levels of saturated fats, and cholesterol (29). Therefore, HMMA are gaining attention from consumers as healthy, nutritionally balanced, and lower cost foods (33).

The main feature of HMMA is that they have a fibrous structure (Fig. 1) similar to that of muscle meat, which has not been accomplished using traditional techniques. Along with the ability of HMEC to create fibrous structures in meat analogues that are similar to animal meats, expectations for greater consumer acceptance of HMMA are rising. Greater acceptance would potentially slow the increase of animal meat production and provide a more environmentally friendly plant protein supply (1).

HMEC is a continuous process using a co-rotating twin-screw extruder. The raw materials are fed into the inlet hopper at the beginning of the extruder barrel. Water is injected into the feeding zone using a pump to obtain the desired moisture content within a range of 50 to 70%. The materials then move through the screws inside the extruder barrel and are mixed, kneaded, and conveyed to the die outlet. For HMEC, the desired extruder barrel temperature is usually between 150 and 170°C, with a high shear pressure that relies on the screw configuration. The most important tool in HMEC is a long cooling die with a temperature of approximately 20°C that is attached to the end of the extruder barrel. This cooling die is the critical feature that allows for the texturization of meat analogues during HMEC. In different sections of the extruder, plant protein molecules experience various mechanical changes, such as un-



**Fig. 2.** Schematic diagram of a co-rotating intermeshing twin-screw extruder with cooling die and protein texturization mechanism in a high-moisture extrusion process.

folding, realignment, and finally cross-linking, while passing through a cooling die (29). A schematic diagram of a co-rotating twin-screw extruder equipped with a cooling die and texturization mechanisms of plant proteins starting from raw material up to the final product state is shown in Figure 2. An HMMA sample exiting a cooling die is shown in Figure 3.

One of the important factors influencing the purchasing choices of consumers is the similarity of HMMA and meat products in terms of textural properties. Comparing the textural properties of beef, pork, and chicken (28) with meat analogues, significantly higher springiness values were observed for meat analogues compared with boiled meat (Table I). However, the hardness and cutting strength values were lower in meat analogues formulated with soy protein isolate, wheat gluten, and corn starch. The cohesive and viscoelastic properties of the wheat gluten in the formulation might have contributed to the chewy texture of meat analogues with higher springiness and lower hardness values after extrusion (27). Among samples, HMMA formulated with a mixture of soy protein isolate, wheat gluten, and corn starch (50:40:10) and extruded under 70% feed moisture, 160°C barrel temperature, and 200 rpm screw speed showed the greatest similarities in hardness and longitudinal cutting strength to boiled chicken meat.

### Texture Stability of HMMA after Cooking

Increasing demand for meat in Asia, where land and water resources are quite limited, will certainly affect Asians in terms of food safety, health, and social responsibility concerns, animal disease threats, environmental pollution from animal metabolism, and high production costs in the animal industry (20). In

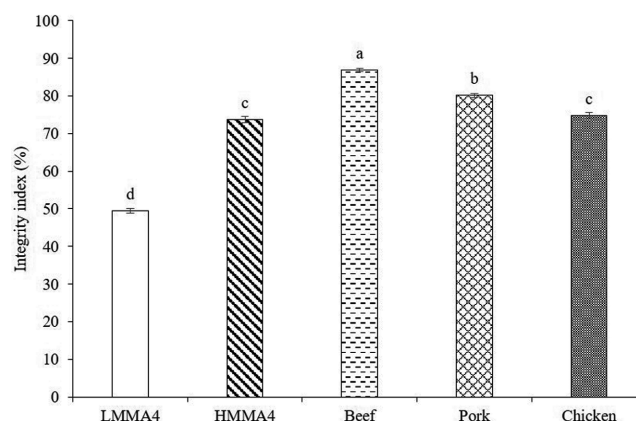


**Fig. 3.** A high-moisture meat analogue sample exiting a cooling die.

this regard, HMMA will have a good opportunity of becoming important meat substitutes in Asia. Therefore, it is essential to study how Asian countries usually consume meat and how meat analogues produced using HMEC could be suitable for Asian cooking styles, which is completely different from Western styles.

As mentioned earlier, South Koreans prepare meats mostly in soups, while Chinese and Japanese deep-fry or steam meats. Therefore, if HMMA are intended to serve as substitutes for muscle meats in Asian markets, matching their cooking stability and textural stability after heating will be key challenges for food scientists. Several researchers have already proven that HMEC technology can successfully create meat analogues with a texture similar to that of muscle meat using plant proteins (2,5,17,18,25,26,34). However, studies on the texture stability of meat analogues after cooking are very limited. Although there are other challenges for HMMA, such as imitating the flavor of meat, marbled texture, color, juiciness, and so on, this study focuses on the texture stability of HMMA.

The texture stability of HMMA after cooking in water using an autoclave or microwave was reported by Samard et al. (29). The authors reported that the texture stability of HMMA decreased only slightly after microwaving, while the opposite results were observed after autoclaving. In HMMA with added wheat gluten, when microwave time was prolonged to 1, 2, and 3 min the samples showed increasing trends in hardness and cutting strengths. Shrinkage of fiber structures due to water loss



**Fig. 4.** Integrity index of meat analogues and different types of boiled meats. LMMA4: low-moisture meat analogue formulated with soy protein isolate, wheat gluten, and corn starch (50:40:10) at 200 rpm; HMMA4: high-moisture meat analogue formulated with soy protein isolate, wheat gluten, and corn starch (50:40:10) at 200 rpm. Different letters above columns indicate significant differences ( $P < 0.05$ ). Values are means of triplicate  $\pm$  standard deviation. (Reproduced, with permission, from Samard [28])

**Table I.** Texture of meat analogues and different types of boiled meats<sup>a,b</sup>

Sample	Springiness (%)	Hardness (g)	Cutting Strength (g/cm <sup>2</sup> )	
			Transversal Direction	Longitudinal Direction
LMMA4	86.51 $\pm$ 0.85 <sup>a</sup>	3,997.52 $\pm$ 53.80 <sup>e</sup>	362.51 $\pm$ 16.00 <sup>e</sup>	292.11 $\pm$ 16.12 <sup>e</sup>
HMMA4	83.37 $\pm$ 0.53 <sup>b</sup>	6,278.19 $\pm$ 24.47 <sup>d</sup>	495.69 $\pm$ 15.79 <sup>d</sup>	452.04 $\pm$ 18.48 <sup>d</sup>
Beef	66.17 $\pm$ 1.65 <sup>d</sup>	8,803.16 $\pm$ 65.17 <sup>a</sup>	1,378.32 $\pm$ 48.24 <sup>a</sup>	1,090.56 $\pm$ 62.03 <sup>a</sup>
Pork	70.70 $\pm$ 0.55 <sup>c</sup>	7,552.62 $\pm$ 94.66 <sup>b</sup>	1,093.76 $\pm$ 35.43 <sup>b</sup>	851.11 $\pm$ 41.70 <sup>b</sup>
Chicken	55.16 $\pm$ 0.95 <sup>e</sup>	6,631.79 $\pm$ 10.00 <sup>c</sup>	751.50 $\pm$ 11.81 <sup>c</sup>	575.55 $\pm$ 25.41 <sup>c</sup>

<sup>a</sup> Data reproduced, with permission, from Samard (28).

<sup>b</sup> LMMA4: low-moisture meat analogue formulated with soy protein isolate, wheat gluten, and corn starch (50:40:10) at 200 rpm; HMMA4: high-moisture meat analogue formulated with soy protein isolate, wheat gluten, and corn starch (50:40:10) at 200 rpm. Values in the same row followed by different letters (a–e) are significantly different at  $P < 0.05$ . Values are means of 10 replicates  $\pm$  standard deviation.



might be the reason for this denser, harder texture with extended microwave time. HMMA samples with wheat gluten had denser, more fibrous, and meat-like structures than those with no added gluten. This may have been related to the ability of gluten to form hard, compact structures.

The cooking stability of meat analogues can be investigated by testing their integrity index. The integrity index was obtained using the residue texture after hydrating, autoclaving,

homogenizing, and drying meat analogues (29). In Figure 4 the integrity index of LMMA, HMMA, and boiled meats are compared. The integrity index of HMMA was similar to that of chicken meat, with no significant difference.

HMMA showed similar hardness, cutting strength, and integrity index to that of chicken. This was due to the well-defined fibrous and layered structure of HMMA. Its fiber arrangement was close to that of pork and chicken meat (Fig. 5).

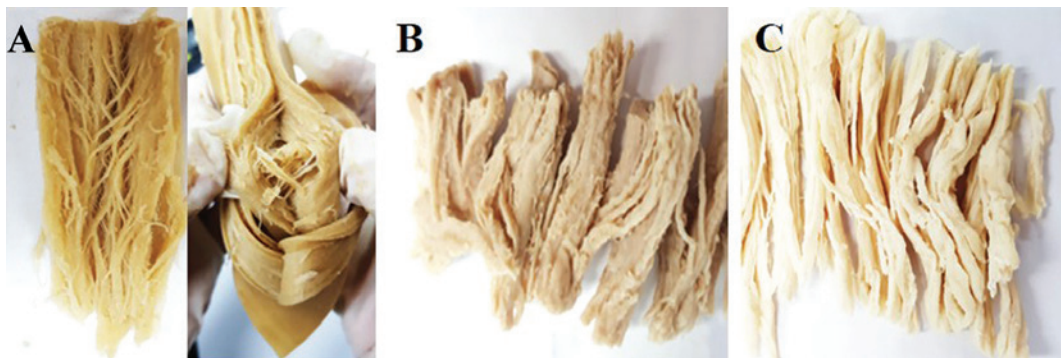


Fig. 5. Digital images of high-moisture meat analogues (A), pork (B), and chicken (C). (Adapted, with permission, from Samard [28])

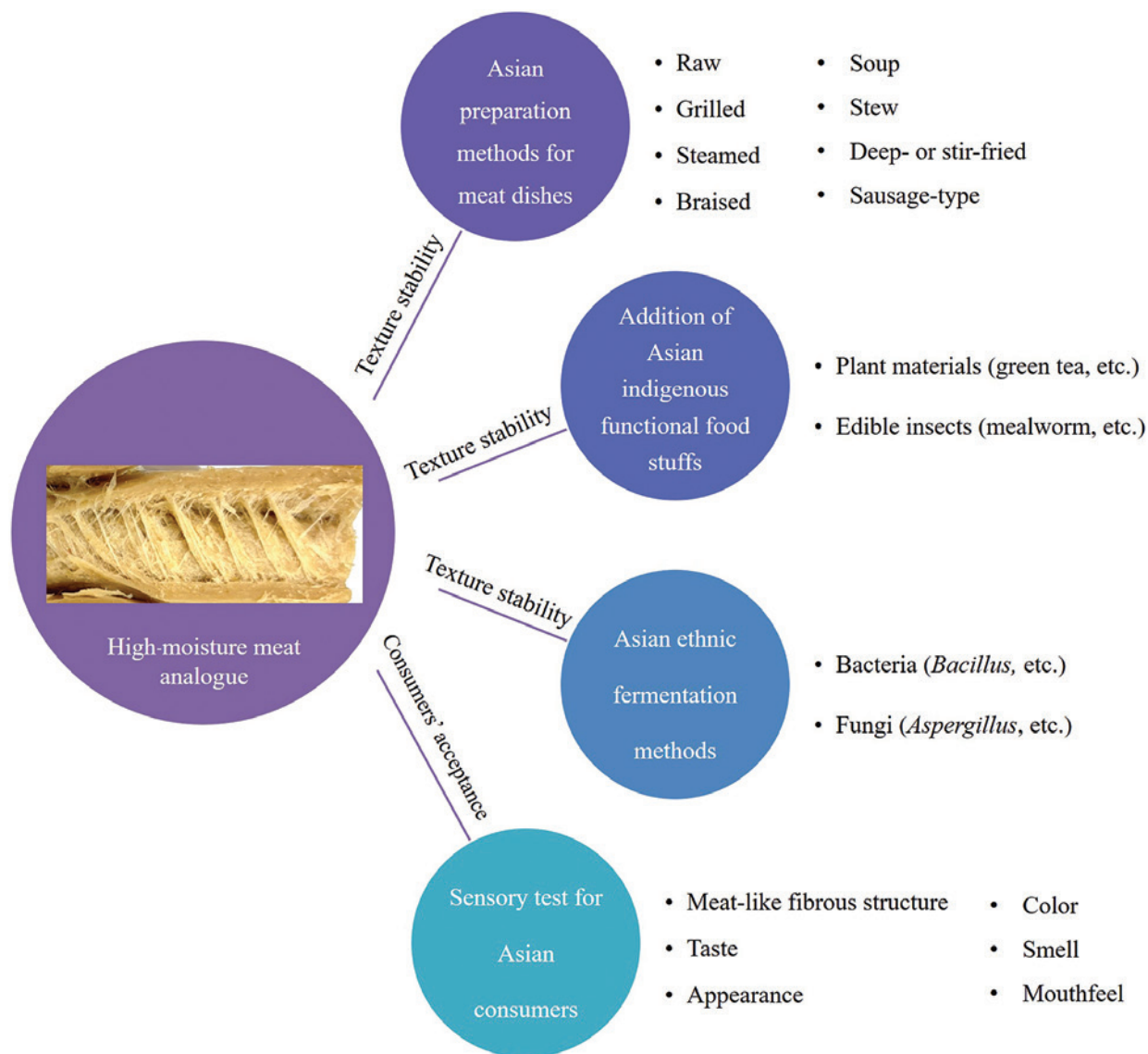


Fig. 6. Aspects of consumer acceptance of high-moisture meat analogues in Asia.

## Aspects of Future Consumer Acceptance of HMMA in Asia

The future research needs for enhancement of HMMA consumption in Asia are summarized in Figure 6. For food scientists, one of the most critical challenges is to maintain HMMA texture after a long cooking time. Currently, there is very limited research on the cooking stability of HMMA, and only one study by Samard et al. (29) at the time this article went to press. However, these results support the future of HMMA, especially in Asia. Another aspect to consider is that Asian people have consumed fermented foods since ancient times. Fermented foods have a long history, and there are more than 100 kinds of fermented foods consumed across Asia. Therefore, it is worth attempting to ferment HMMA because it might draw the attention of Asian consumers. In addition to fermented foods, consumption of green tea, which is rich in polyphenols, especially catechins, is popular in Asia. Asia is also a region in which high numbers of edible insects are consumed. Over 1,000 insect species are consumed and play an essential part in food security. Similar studies on incorporating these types of indigenous Asian foodstuffs (e.g., green tea and edible insects) in HMMA show promise for promoting HMMA consumption in Asia. Additionally, comparative studies on consumer acceptance are necessary. For example, HMMA is very similar in appearance to a popular Korean side dish known as *jangjorim*, a soy braised beef. Understanding and finding ways to develop HMMA-based products that fit with Asian dining habits are critical to stimulate changes for a better and healthier future.

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**The-Thiri Maung** is currently a Ph.D. candidate in food engineering under the supervision of Professor Gi-Hyung Ryu at Kongju National University (KNU), South Korea. Her research area is focused on high-moisture extrusion of meat analogues. The research is intended to develop soy protein-based meat analogues with highly fibrous and well-defined layered structures to imitate animal meats. She is also conducting experiments on fermentation of low- and high-moisture meat analogues using *Bacillus subtilis*. Since 2012,

The-Thiri has been working as an assistant lecturer at Yezin Agricultural University (YAU), Myanmar.



**Gi-Hyung Ryu** is currently the president of the graduate school and a professor at Kongju National University (KNU), South Korea. He attained his Ph.D. degree in food science from the Kansas State University, U.S.A. Gi-Hyung has more than 30 years of teaching and research experiences in food extrusion, food engineering, and cereal processing. He also has worked as a visiting/research professor at Cornell University, NY, U.S.A., and Michigan State University, U.S.A., and the University of Manitoba, Canada. He has published

195 research articles, 17 books, and 34 patents, both internationally and in South Korea. He has supervised 90 B.S. and 100 M.S. and Ph.D. graduates, including international students. His professional interests are nutraceuticals in cereals and plants, extrusion texturization of low- and high-moisture meat analogues, microencapsulation and pelleting, release control of nutraceuticals in extruded pellets, extrusion with supercritical carbon dioxide, the puffing mechanism of cereals, RVA and NIR for extrudate quality control, and extrusion reaction for bioconversion.