Utilization of Rice Husk for Production of Multifunctional Liquid Smoke

R. Risfaheri[1], H. Hoerudin[1], and M. Syakir[2]
[1] Indonesian Center for Agricultural Postharvest Research and Development, Bogor, Indonesia
[2] Indonesian Agency for Agricultural Research and Development, Indonesia
Email: risfaheri1964@gmail.com

***Abstract*—Rice husk is an abundant and underutilized by-product of rice milling industries, especially in main rice producing countries like Indonesia. The current challenge is how to contribute value addition to the rice milling industries by maximizing utilization of the unwanted rice husk. Recently, there has been a growing interest in utilizing rice husk for production of multifunctional liquid smoke. However, limited studies have been done on this aspect. Previous published reviews are mostly focused on development of liquid smoke from different wood varieties/types or palm oil waste. The main objective of this review is to provide a comprehensive review and further research direction regarding potential development and applications of liquid smoke from rice husk based on the limited and scattered information currently available. This review covers production technology, characteristics, functional properties and potential applications of rice husk liquid smoke. The cited findings showed that there are are at least four pyrolysis techniques that can be used for production of rice husk liquid smoke. In addition, there are several factors that may influence the qulaity of the final product. These include modes of pyrolysis (temperature, heating rate, residence time), biomass composition, and storage condition and period. Each technique and factor can be adjusted and exploited to extract and produce value-added liquid smoke by thermal processing. Rice husk liquid smoke has multifunctional properties, such as antioxidant, anti-inflammatory, antimicrobial and antidiabetic. Composition of major constituents in rice husk liquid smoke determines the magnitude of its functional properties and potential applications. Based on its functional properties, rice husk liquid smoke has a great potential for food and agriculture applications, such as food flavorings, food preservatives, biopesticides, and plant growth regulator. This review will be valuable for both industries and communities. Utilization of rice husk for production liquid smoke will not only benefit rice milling industries and farmers, but also the environtment.**

***Index Terms*—rice husk, by-product, liquid smoke, pyrolysis, utilization**

I. INTRODUCTION

Rice (*Oryza sativa* L.) is one of staple foods for the world's population, especially in Asia, Africa, and Latin America. In 2017 world production of paddy is predicted to reach around 759 million tonnes. Indonesia is the third largest rice producing country in the world [1]. Indonesia production of paddy in 2017 is estimated about 77 million tonnes (Ministry of Agriculture, The Republic of Indonesia) or around 10% of the world production. Rice husk is an abundant rice milling by-product accounting for 20% of the unhulled paddy [2], [3]. Annually, Indonesia produces nearly 16 million tonnes of rice husk that is mostly underutilized and becoming a serious problem for rice processing industries.

Rice husk can be classified as a complex lignocellulosic material. It contains cellulose (26-36%), hemicellulose (12-32%), lignin (15-23%), ash (13-23%), and crude protein (2-3%) [4]-[8]. However, Sung, Stone & Sun [8] studied the lignocellulosic composition of three rice husk varieties from USA and they found that the lignocellulosic composition was relatively similar among the three rice husk varieties. One of the most popular applications of rice husk in Indonesia is used as a heat energy source for drying. In this case, rice husk is incinerated and the heat generated is used to dry brick or unhulled paddy. During the incinerating and drying process, smoke generated usually goes to the surrounding air and may result in air pollution.

Separate previous studies showed that the smoke from rice husk incineration and residual rice husk ash may be utilized for production of new valuable products, i.e. rice husk liquid smoke [8]-[11]. Rice husk liquid smoke has been reported to have a number of functional properties, such as antimicrobial [6], [12], antioxidant [5], anti-inflammation [9], and antidiabetic [7]. Such multifunctional properties enable rice husk liquid smoke to be used for natural insecticide [10], [13], preservative [11] or disinfectant [12].

Recently, there has been a growing interest in utilizing rice husk liquid smoke for production of new valuable products. In addition, previous published reviews are mostly focused on development of liquid smoke from different wood varieties/types [14] or palm oil biomass [15]. On the other hand, reviews on development of rice husk liquid smoke and its derivative products have not been much studied. This article provides a comprehensive review and further research direction regarding potential development and applications of liquid smoke from rice husk. The described findings may have practical implications for food and agriculture sectors, including but not limited to healthier foods, improved human health, and more developed rice processing industries.

Manuscript received October 24, 2017; revised April 23, 2018.

©2018 Journal of Advanced Agricultural Technologies

doi: 10.18178/joaat.5.3.192-197

II. PRODUCTION OF RICE HUSK LIQUID SMOKE

A. Processing

Rice husk liquid smoke is basically produced through a pyrolysis process. Pyrolysis of lignocellulosic biomass is a thermal degradation process of organic matter containing hemicellulose, cellulose and lignin through burning or heating process in the absence of air or other molecular oxygen containing gases [16]. Dried rice husk is incinerated and smoke is produced. The resulting smoke is collected and directed to a liquefaction pipe passing through a cooling tank. Once condensation occurs, the smoke is converted to a liquid form along the cooled pipeline. The final product, which is rice husk liquid smoke, has a smoky aroma and sugar-like odor. To separate insoluble materials, the liquid smoke could be left standing for about one week at room temperature. The supernatant is colected as the primary rice husk liquid smoke extract. In general, biomass pyrolysis involves decomposition, oxidation, polymerization, and condensation [16]. Biomass pyrolysis produces three types of products, which are (i) liquid (distillates of volatile condensable compounds), (ii) non-condensable gases, and (iii) solid char [14].

Generally, there are four types of pyrolysis, namely carbonization (slow pyrolysis), torrefaction, intermediate, and fast pyrolysis. The four main pyrolysis techniques have different indicating conditions dan compositions of their major products (Table I). Carbonization is a conventional pyrolysis process characterized by a low heating rate (>1 ℃/s) and a long solid residence time (hours until days) that favours the production of char. Appropriate slow pyrolysis may produce by-products such as acetic acid and tars (dark and oily material) [16]-[18]. Rice husk liquid smoke is commonly produced at farm level through this type of pyrolysis process, especially in Indonesia.

TABLE I. TYPES OF PYROLYSIS AND THE CORRESPONDING COMPOSITION OF MAJOR PRODUCTS

Types	Composition (%)		
	Liquid	Solid	Gas
Carbonization	30	33 Char	35
Torrefaction	0-5	77 Solid	23
Intermediate	50	25 Char	25
Fast	75	12 Char	13

Adapted from de Wild *et al.* [16]

Torrefaction is a pyrolysis type with a mild thermal treatment (~290 ℃) with heating rate >1 ℃/s and solid residence time ~30min. During torrefaction, lignocellulosic biomass is transformed into a solid material. In comparison to the initial biomass, the solid material produced has a higher energy density, a better grindability and a lower moisture susceptibility. As a result, it can be used for an enhanced heat and power generation [16], [19]. Intermediate pyrolysis applies a thermal-conversion technique (400-500 ℃) with heating rate 1-1,000 ℃/s and hot vapor residence time ~10-30s. The intermediate pyrolysis generates a higher amount of liquid product from biomass than carbonization and torrefaction. Finally, fast pyrolysis is a thermal conversion-technique indicated by a relatively high temperature (500 ℃), heating rate >1,000^{o}C/s and hot vapor residence time ~1s.

The pyrolysis conditions facilitate conversion of biomass into a liquid product. The fast pyrolysis yields a higher fraction of the liquid product than the other three types of pyrolisis. The liquid product, which is also called pyrolysis-oil or bio-oil, can be used for both heat/power generation and a feedstock for chemicals [14], [16].

B. Factors Affecting Yield

Specific studies on factors affecting rice husk liquid smoke yield have not been done extensively. Therefore, there are limited published literatures. Previous studies reported that rice husk liquid smoke yield is influenced by biomass type [10] and pyrolysis temperatures [12]. Mustikawati *et al.* [10] found that slow pyrolysis of rice husk (160^{o}C, 11h) yielded a lower amount of liquid smoke (10,80% of the rice husk weight) than that of coconut shell (13,12%) and wood (12,63%). The differences in liquid smoke yield may be due to differences in the composition of lignin, cellulose and hemicellulose (the main biomass constituents) in rice husk, coconut shell and wood. Then, according to Sukharnikov *et al.* [12] the yield of rice husk liquid smoke generally increased with the pyrolysis temperatures (Fig. 1). It is shown that The yield increased gradually when the liquid smoke generated at temperature below 400^{o}C. The yield of rice husk liquid smoke increased drastically between 400^{o}C and 500^{o}C. There was a yield increase of 23% when the pyrolysis temperature was raised from 300^{o}C to 500^{o}C [12].

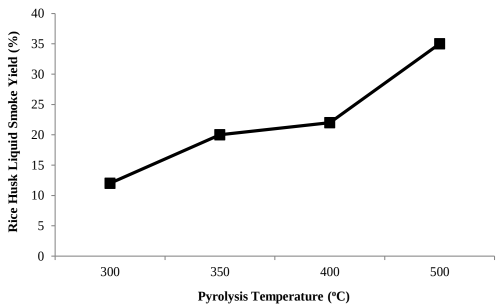

Figure 1. Effect of pyrolysis temperature on rice husk liquid smoke yield (Adapted from Sukharnikov *et al.* [12])

III. CHARACTERISTICS OF RICE HUSK LIQUID SMOKE

A. General Characteristics

General characteristic and composition of biomass liquid smoke are influenced by many factors, including modes of pyrolysis (temperature, heating rate, residence time), biomass composition, and storage period [8], [9], [16], [20], [21]. Chemical and physical characteristics of rice husk liquid smoke are presented in Table II. Previous studies showed that rice husk liquid smoke has a relatively low pH, ranging from 2,3 to 3,0 [8]-[10]. The pH of rice husk liquid smoke (pH 3.0) was even lower than that of coconut shell (pH 4,0) and wood (pH 3,8) liquid smoke produced using the same pyrolysis mode and conditions [10]. Our unpublished work showed that the pH of rice husk liquid smoke decreased following distillation. This may be due to increased concentration of condensable acid fractions. Sung *et al.* [8] observed that the color of rice husk liquid smoke changed from initial light yelow to dark brown within two weeks of storage. This was shown by the decrease in lightness (L-value) with storage time. The color changes were consistent among three rice husk varieties studied [8] and the changes could be due to oxidation of phenolic compounds [22]. Then, a brown layer of precipitates is commonly settled following sedimentation/storage of rice husk liquid smoke. Presumably, the precipitate consists of lignin monomers and dimmers [23]. The pungent odor may come from phenol, methylphenol and 2.4-dimethylphenol present in the rice husk liquid smoke.

TABLE II. CHEMICAL AND PHYSICAL CHARACTERISTICS OF RICE HUSK LIQUID SMOKE

Properties	Value/Description	References
pH	2.3 - 3,0	[8]-[10]
Specific gravity	1.007	[9]
Fresh color	Light yellow	[8]
Aroma	Smoky	[9]
Odor	Pungent, burnt-sugar like	[8], [9]
Solubility	Partially soluble in water, highly sobule in alcohol, partially soluble in in ether	[12]

B. *Composition*

Table III summarizes main chemical composition of rice husk liquid smoke that has been published in different studies previously. In general, phenolic and furan compounds are the major volatile constituents of rice husk liquid smoke produced at pyrolysis temperature of 330 ℃ and 450-500 ℃ [8], [9]. The phenolic compounds account for about 85% of the main volatile constituents identified in rice husk liquid smoke [8]. Similarly, Guillen *et al.* [24] reported that the proportion of phenol derivatives in commercial liquid smoke was approximately 65%. However, Mustikawati *et al.* [10] found that rice husk liquid smoke produced at pyrolysis temperature of 160 ℃ contains mainly acetic acid, accounting for 76% of the major volatile constituents characterized. The proportion of acetic acid in rice husk liquid smoke was higher than that in coconut shell and wood liquid smoke (each around 53%). Meanwhile, rice husk liquid smoke had a lower proportion of phenol and phenol derivatives (12%) in comparison to coconut shell and wood liquid smoke (each about 20%) [10]. Such different results may be due to differences in the pyrolysis temperature set as well as the composition of main constituents in rice husks used. Lignin and cellulose are degraded at temperature of 200 ℃ or higher. Lignin and cellulose are the main source of phenolic and furan compounds [25]-[27]. Meanwhile, at pyrolysis temperature of 160 ℃ (below 200 ℃) the predominant biomass constituent degraded is hemicellulose, which is the major source of acetic acid [15], [16]. Nevertheless, appropriate thermal degradation may also transform hemicellulose into furan, furan derivatives [15], [28].

TABLE III. FIVE MAJOR COMPOUNDS IN RICE HUSK LIQUID SMOKE FROM DIFFERENT STUDIES

Pyrolisis Temperature (°C)	Number of Compounds Specified	Five Majoer Compounds	References
450 - 500	161 Volatiles	Phenol; 2,4,-dimethyl-3-(methoxycarbonyl)-5-ethylfuran; 2,6-dimethoxyphenol; 16-keto-tetrahydrosolasodine; benzencarboxylic acid	[9]
330	8 Major Volatiles	2-Methoxy-4-methylphenol (4-Methylguaiacol); 2-Ethylphenol; 4-Ethyl-2-methoxyphenol (4-Ethylguaiacol); 4-Methoxyphenol; 2-Mehtoxy-4-vinylpheonl	[8]
160	16 Major Volatiles	Acetic acid (CAS) Ethylic acid; Phenol, 2-methoxy-(CAS) Guaiacol; Acetic acid, Anhydride with Formic Acid; 2-Methoxy-4-methylphenol; Phenol, 3-ethyl-(CAS) m-Ethylphenol	[10]

The proportion of major volatile compounds in rice husk liquid smoke is also influenced by the pyrolysis temperatures [8]. This may be due to the fact that hemicellulose, cellulose and lignin (the main biomass constituents) transform in different ways at various temperatures and thus they produce unique volatile compounds [16], [29]. Fig. 2 shows the effect of different temperatures on the proportion of three major volatile compounds in liquid smoke produce from the same rice husk. The percentage of the 2-ethylphenol increases consistently with temperatures. Conversely, percentage of the 2-Methoxy-4-methylphenol (4-methylguaiacol) decreases drastically from 250 ℃ to 330 ℃. The 4-methoxy-phenol content is relatively stable at 200 ℃ and 250 ℃, but the increases gradually at 330 ℃. Fenner & Lephardt [30] found that maximum formation of guaiacol and 2-methoxy-4-alkyl-substituted phenols took place at temperature of 385 ℃. As a result, the proportions of the three major volatiles in rice husk liquid smoke at 200 ℃ and 330 ℃ are different. The data suggest that generation temperatures can be used to control concentrations of the desired constituents present in the rice husk liquid smoke.

The effect of rice husk varieties, storage, and the presence of oxygen or air on the composition of rice husk liquid smoke has also been reported. Sung *et al.* [8] demonstrated that the main volatile compounds present in liquid smoke did not vary with the rice varieties of the original rice husk. Although this may be due to the same or similar composition of lignin, cellulose, and hemicellulose in the rice husk varieties tested. In other words, different results may be obtained when the compositions of lignin, cellulose, and hemicellulose in the rice husk varieties are widely different. The composition of rice husk liquid smoke remained the same after a 6-week refrigerator storage. If adequate air is present during the preparations, oxygenated compounds such as vanillin, vanillic acid, guaiacol, and aceto-vanillone would be formed and present in the rice husk liquid smoke [8].

IV. Functional Properties and Applications of Rice Husk Liquid Smoke

A. *Functional Properties*

Functional properties of rice husk liquid smoke have been the subjects of various studies recently. Rice husk liquid smoke has been reported to have antioxidant [5], [31], anti-inflammatory [9], antimicrobial [6], [12] and antidiabetic properties [7], [32]. Salanti *et al.* [5] tested the radical scavenging activity of acidolysis and alkaline enzymatic lignins from rice husk, expressed as IC_{50} (the half-maximal inhibitory concentration). The results showed that IC_{50} values of the lignin samples were found to be overall similar to those of reference antioxidants (quercetin, rutin, BHA, BHT). This suggests that lignin derivatives from rice husk exhibited antioxidant acitivity. Then, Huang *et al.* [31] examined the antioxidant activities of three prominent methoxyphenols of liquid smoke flavouring, from rice hull, which are 4-Methoxyphenol (4-MP), 4-ethyl-2-methoxyphenol (EMP) and 4-propenyl-2-methoxyphenol (isoeugenol). EMP displayed the highest inhibitory effects on radical production and biomolecule oxidation in the acellular systems. The three smoke flavouring phenols also decreased nitric oxide production. The results showed the antioxidant activity of the three phenols.

The anti-inflammatory property of rice husk liquid smoke was examined by Kim *et al*. [9]. The extract from rice husk liquid smoke was administered through topical application of 1% of the extract to skin inflammation of mice or feeding mice with a standard diet with 1% extract for two weeks. Administration of the extract significantly reduced the expression of biomarkers associated with the TPA-induced inflammation. The results showed the anti-inflammatory activities of the rice husk liquid smoke extract.

The rice husk liquid smoke have been tested for antimicrobial activities in previous studies. The phenols, acids and alcohol fractions of rice husk liquid smoke showed bactericidal and fungicidal activities. The phenol fraction exhibited the highest activities, followed by alcohol fraction and acid fraction [12]. The rice husk liquid smoke also assayed for bactericidal activity against the foodborne pathogen, *Salmonella Typhimurium*. The bactericidal activity was tested *in vitro* and *in vivo* using a Salmonella-infected Balb/c mouse model. The results showed that the rice husk liquid smoke extract exhibited inhibitory activity to the bacterial growth, comparable to that of the medicinal antibiotic vancomycin. The most effective way for the antibacterial activity of rice husk liquid smoke extract was 4 consecutive administrations at 12-h intervals that reduced bacterial growth by 75.0%. The inhibitory activity of rice husk liquid smoke extract to the bacterial growth may result from the low pH value. *In vivo* study using mice infected with lethal doses of the Salmonella showed that the use of 1.0% v/w of rice husk liquid smoke extract protected the liver tissues against Salmonella-induced pathological necrosis lesions and thus decreased mice mortality [6].

The antidiabetic effect of rice husk liquid smoke was investigated using mice fed with a high-fat diet. Dietary administration of 0.5 or 1% of the liquid smoke lasted for 7 weeks. The results showed that dietary administration of the rice husk liquid smoke restored (i) glucose-regulating molecule activities to normal control levels, (ii) necrotic damage in the liver to normal levels, and (iii) the reduced insulin-producing β-cell population of the pancreas associated with a high-fat diet intake to nondiabetic normal control levels [7], [11], [32].

B. *Potential Applications*

Based on its functional properties, rice husk liquid smoke has a great potential for food and agriculture applications. Application of liquid smoke for food uses, such as flavorings, is currently gaining acceptance in food industries since it has a number of advantages over the traditional smoking practices. Liquid smoke can be prepared and applied much easier with more consistent results [11]. Foods flavored with liquid smoke contain a much lower concentration of polycyclic compound [33]. Liquid smoke contributes a more uniform food flavor and color, enables to control smoke intensity in foods [34], and reduce smoke pollution. Because of such advantages, the wood-derived liquid smoke has been used as flavorings in foods [11]. In this case, the rice husk liquid smoke may be used as a new source of liquid smoke flavorings for food applications. However, since the chemical constituents of rice husk liquid smoke may vary widely and the compounds responsible for the observed bioactivity are still not fully identified, evaluation of the all safety aspects of rice husk liquid smoke needs to be done prior to its recommendation for food uses.

In agriculture sector, application of rice husk liquid smoke as an insecticide to soybean plant was demonstrated by Mustikawati *et al.* [10]. In this study, the efficacy of liquid smoke generated from rice husk, coconut shell and wood on soybean pests, armyworm (*Spodoptera* sp.), pod borer (*Etiella* sp.), pod sucking (*Nezara viridulla, Riptortus linearis,* and *Piezodorus hybneri*) was compared. The results showed that application of three types of liquid smoke could decrease pest attack significantly and they were equally effective in combating the soybean pests. The percentage of pest attack on soybean plant with liquid smoke treatment was significantly lower as compared to that without liquid smoke treatment. The efficacy of the three types of liquid smoke was comparable to that of the commercial/synthetic pesticide used in the study. The efficacy of the rice husk liquid smoke may result from the bioactives acting as as antimicrobial or toxicants for the insect pests of Lepidoptera. Previous data also show that rice husk liquid smoke produced at temperature

©2018 Journal of Advanced Agricultural Technologies

160 ℃ consists mainly of acetic acid. According to Yatagai *et al.* [18], acetic acid play an important role in accelerating the plant growth. Therefore, rice husk liquid smoke can be used for both insecticides and plant growth regulator. Each major volatile compounds in the rice husk liquid smoke may have different antimicrobial or efficacy to insect pests or fungi. These aspects merit further study for development of bioinsecticides or fungicides from rice husk liquid smoke.

REFERENCES

[1] Food and Agriculture Organization of the United Nations, *Rice Market Monitor*, July 2017, vol. 20, no. 2.

[2] K. Y. Foo and B. H. Hameed, "Utilization of rice husk ash as novel adsorbent: A judicious recycling of the colloidal agricultural waste," *Advances in Colloid and Interface Science*, vol. 152, pp. 39-47, 2009.

[3] V. H. Le, C. N. H. Thuc, and H. H. Thuc, "Synthesis of silica nanoparticles from Vietnamese rice husk by sol–gel method," *Nanoscale Research Letters*, vol. 8, no. 1, pp. 58-58, 2013.

[4] I. B. Ugheoke and O. Mamat, "A critical assessment and new research directions of rice husk silica processing methods and properties," *Maejo International Journal of Science and Technology*, vol. 6, no. 3, pp. 430-448, 2012.

[5] A. Salanti, L. Zoia, M. Orlandi, F. Zanini, and G. Elegir, "Structural characterization and antioxidant activity evaluation of lignins from rice husk," *Journal of Agricultural and Food Chemistry*, vol. 58, pp. 10049-10055, 2010.

[6] S. P. Kim, M. Y. Kang, J. C. Park, S. H. Nam, and M. Friedman, "Rice hull smoke extract inactivates salmonella typhimurium in aboratory media and protects infected mice against mortality," *Journal of Food Science*, vol. 77, pp. M80-M85, 2012.

[7] J. Y. Yang, M. Y. Kang, S. H. Nam, and M. Friedman, "Antidiabetic effects of rice hull smoke extract in alloxan-induced diabetic mice," *Journal of Agricultural and Food Chemistry*, vol. 60, pp. 87-94, 2012.

[8] W. C. Sung, M. Stone, and F. M. Sun, "Analysis of volatile constituents of different temperature rice hulls liquid smoke," *Cha-Nan Annual Bulletin*, vol. 33, pp. 1-12, 2007.

[9] S. P. Kim, *et al.*, "Composition of liquid rice hull smoke and anti-inflammatory effects in mice," *Journal of Agricultural and Food Chemistry*, vol. 59, pp. 4570-4581, 2011.

[10] D. R. Mustikawati, N. Mulyanti, and R. W. Arief, "Study effectiveness of liquid smoke as a natural insecticide for main pest control of soybean crops," *International Journal of Sciences: Basic and Applied Research*, vol. 30, no. 1, pp. 237-245, 2016.

[11] M. Friedman, "Rice brans, rice bran oils, and rce hulls: Composition, food and industrial uses, and bioactivities in humans, animals, and cells," *Journal of Agricultural and Food Chemistry*, vol. 61, pp. 10626-10641, 2013.

[12] Y. Sukharnikov, *et al.*, "Production, properties and use of the rice hulls pyrolysis organic product as a disinfectant," *World Journal of Veterinary Medicine & Engineering*, vol. 1, no. 1, pp. 1-9, 2015.

[13] F. Wagiman, A. Ardiansyah, and Witjaksono, "Activity of coconut-shell liquid-smoke as an insecticide on the rice brown planthopper (nilaparvata lugens)," *ARPN Journal of Agricultural and Biological Science*, vol. 9, no. 9, pp. 293-296, 2014.

[14] K. Tiilikkala, L. Fagernäs, and J. Tiilikkala, "History and use of wood pyrolysis liquids as biocide and plant protection product," *The Open Agriculture Journal*, vol. 4, pp. 111-118, 2010.

[15] Risfaheri, "Prospek asap cair sebagai pestisida nabati," in *Prinsip-Prinsip dan Teknologi Pertanian Organik*, A. Kardinan, Ed., Jakarta: IAARD Press, 2014, pp. 67-76.

[16] P. D. Wild, H. Reith, and E. Heeres, "Biomass pyrolysis for chemicals," *Biofuels*, vol. 2, no. 2, pp. 185-208, 2011.

[17] Y. Chalermsan and S. Peerapan, "Wood vinegar: By-Product from rural charcoal kiln and its role in plant protection," *Asian Journal of Food and Agro-Industry*, vol. 2, pp. S189-S195, 2009.

[18] M. Yatagai, M. Nishimoto, K. Hori, T. Ohira, and A. Shibata, "Termiticidal activity of wood vinegar, its components and their homologues," *Journal of Wood Science*, vol. 48, no. 4, pp. 338-342, 2002.

[19] M. J. Prins, K. J. Ptasinski, and F. J. J. G. Janssen, "More efficient biomass gasification via torrefaction," *Energy*, vol. 32, pp. 3458-3470, 2006.

[20] T. Nakai, S. N. Kartal, T. Hata, and Y. Imamura, "Chemical characterization of pyrolysis liquids of wood-based composites and evaluation of their bio-efficiency," *Building and Environment*, vol. 42, no. 3, pp. 1236-1241, 2007.

[21] S. K. Schwanke, W. G. Ikins, and M. S. Brewer, "Phenol compounds identified in selected liquid smokes," *Journal of Food Lipids*, vol. 2, pp. 239-247, 1995.

[22] J. A. Maga, "The flavor chemistry of wood smoke," *Food Reviews International*, vol. 3, pp. 139-183, 1987.

[23] M. D. Guillen and M. L. Ibargoitia, "Gc/Ms analysis of lignin monomers, dimmers and trimers in liquid smoke flavourings," *Journal of the Science Food Agriculture*, vol. 79, pp. 1889-1903, 1999.

[24] M. Guillen, M. Manzanos, and L. Zabala, "Study of a commercial liquid smoke flavoring by means of gas chromatography/ mass spectrometry and fourier transform infrared spectroscopy," *Journal Agriculture Food Chemistry*, vol. 43, pp. 463-468, 1995.

[25] S. Soldera, N. Sebastianutto, and R. Bortolomeazzi, "Composition of phenolic compounds and antioxidant activity of commercial aqueous smoke flavorings," *Journal of Agricultural and Food Chemistry*, vol. 56, pp. 2727–2734, 2008.

[26] L. Toth and K. Potthast, "Chemical aspects of the smoking of meat and meat products," *Advances in Food Research*, vol. 29, pp. 87-158, 1984.

[27] J. A. Maga, *Smoke in Food Processing*, Boca Raton, FL: CRC Press, 1988.

[28] J. Gilbert and M. Knowles, "The chemistry of smoked foods: A review," *Food Technology*, vol. 10, pp. 245-261, 1975.

[29] J. N. Murwanashyaka, H. Pakdel, and C. Roy, "Step-Wise and one-step vacuum pyrolysis of birch-derived biomass to monitor the evolution of phenols," *Journal of Analytical and Applied Pyrolysis*, vol. 60, no. 2, pp. 219-231, 2001.

[30] R. A. Fenner and J. O. Lephardt, "Examination of the thermal decomposition of kraft pine lignin by fourier transform infrared evolved gas analysis," *Journal Agriculture Food Chemistry*, vol. 29, pp. 846-849, 1981.

[31] M. H. Huang, L. W. Chang, W. C. Sung, W. J. Vong, and B. S. Wang, "Protective effects of three smoke flavouring phenols on oxidative damage and nitric oxide production," *Food Chemistry*, vol. 126, pp. 1655-1661, 2011.

[32] J. Y. Yang, E. Moon, S. H. Nam, and M. Friedman, "Antidiabetic effects of rice hull smoke extract on glucose-regulating mechanism in type 2 diabetic mice," *Journal Agriculture Food Chemistry*, vol. 60, pp. 7442−7449, 2012.

[33] V. Varlet, *et al.*, "Organoleptic characterization and pah content of salmon (salmo salar) fillets smoked according to four industrial smoking techniques," *Journal of the Science of Food and Agriculture*, vol. 87, pp. 847–854, 2007.

[34] T. Hattula, K. Elfving, U. M. Mroueh, and T. Luoma, "Use of liquid smoke flavouring as an alternative to traditional flue gas smoking of rainbow trout fillets (oncorhynchus mykiss)," *Lebensmittei-Wissenschaft und Technologie*, vol. 34, pp. 521-525, 2001.

Risfaheri was born in Sawahlunto, West Sumatera, Indonesia on 17 January 1964. He earned his Bachelor degree in Agroindutsrial Technology at Bogor Agricultural University, Bogor, Indonesia in 1986. He completed his Master of Science in Agroindustrial Technology at Bogor Agricultural University in 1999. He received his Doctoral degree (Dr.) in Agroindustrial Technology from Bogor Agricultural University, Indonesia in 2004. His Professor of Research title was obtained from the Indonesian Institutre of Science in 2010. Currently, he is the Director of Indonesian Center for Agricultural Postharvest Research and Development (ICAPRD), Indonesian Agency for Agricultural Research and Development, Ministry of Agriculture of the Republic of Indonesia.

Hoerudin was born in Bogor, Indonesia, on 10 August 1973. He earned his Bachelor degree in soil science at Bogor Agricultural University, Bogor, Indonesia in 1997. He completed his Master of Food lia in 2004. He received his Doctor of Philosophy (PhD) in food science and nutrition from The University of Queensland, Brisbane, Australia in 2012.
Currently, he is the Head of Research Program and Evaluation Division as well as a researcher working for Indonesian Center for Agricultural Postharvest Research and Development (ICAPRD), Indonesian Agency for Agricultural Research and Development, Ministry of Agriculture of the Republic of Indonesia. Previously, he was the biomaterial technology research group leader and the laboratory technical manager at ICAPRD.
Dr. Hoerudin and his colleagues have developed isolation and purification techniques for cellulose nanofiber from agro-waste materials, silica nanoparticles from rice husk. His major research interests are (i) nanoencapsulation of vitamins, minerals, dan bioactives for development of functional foods, (ii) isolation, modification, characterization, and utilization of cellulose nanofibers for food-related applications, (iii) nanoencapsulation of bio-based agrochemicals, and (iv) applications of silica nanoparticles from rice husk for agricultural, food and industrial applications.

M. Syakir was born in Watampone, South Sulawesi, Indonesia on November 17th 1958. He was graduated for first degree in 1985 from Agriculture Faculty, Hasanudin University, Makassar. He earned Master degree in 1990 and Doctor degree in 2005, both from Bogor Agricultural University. Currently he is the Director General for Indonesian Agence for Agricultural Research and Development, Indonesian Ministry of Agriculture. His reseach interest are cultivation technique estates crops, and utilization of waste for cultivation. He is also head of Peragi (Association of Indonesian Agronomist).