Silicon chemistry for sustainable development of rice agriculture

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Abstract. The literature reviewed paper was aimed to explain the role of paddy’s plantation for reserving silica powder, to explain the current developing of advanced materials from the high siliconeous rice plant biomasses, to propose a scheme of value addition of paddy’s biomasses for sustainable rice agriculture development. A comprehensive literature review through meta analysis on articles published in last few decades was conducted. Because of high silicon content of rice biomasses especially rice straws and husks and their abundance in availability, the rich silicon biomasses can be used as raw material for producing a high purity reactive fine powder silica, and unexpensive and environment-friendly production processes. Current development results on advanced materials from the rich siliconeous biomasses were reported, namely silicon carbides, amorphous reactive silica, nanosilica, and silica-carbon nanocomposite. The implementation of silicon chemistry takes important role for enhancing the added value of rice husks and straws as the side products of paddy’s agriculture to produce some advanced materials inexpensively and environment-friendly. The added values can be considered to overcome the problems of lack paddy’s farmer income and the land conversion tendency of rice field, thus the paddy’s agriculture can be developed sustainably.

1. Introduction
Silicon and silica powders, as well as their generative advanced materials todays take more attention industrially. Worldwide market of silica powder, for instance, has increased sharply from 27.8 million metric tonnes at 2004 [1] to ten times about 278 million metric tonnes in year 2016 as predicted by PR Newswire [2]. Mainly, the silica powder was reserved from the earth deposite of high silica content of hardrock such as taconite, granite, and quartzite as well as from quart sand, where both kinds of raw materials needed to be broken down, milled, and physically as well as chemically purified respectively [3]. Those steps of producing silica powder from the rock and sand were high costs for machine investment and energy. It affected the relative expensive of the silica powder price, for instance, in Europe at 2004 the price silica powder reached USD 927/tonne [1]. The mining of rocky silica deposits or quartz sands was also environmental unfriendly, for example, purification processes from metallic impurities used clean water about 4,500 to 6,000 gallons/minute and the throwing away some impurities solvents in the water body [4]. Thus, the production of silica powder from rocks or quartz sands is not only high cost but also environment-unfriendly.

The finding of high silicon content of the rice plant biomasses and the high silica content of rice husk ash triggered further investment intensively among their silica based advanced materials. It is also as a potential alternative solution for supplying silica powder in enough quantity, high purity, and low
cost because the availability of the raw rich siliceous biomasses as reviewed previously [5]. The high potency of rice biomasses can be seen from the annual world production of rice grain about 600 million tonnes, rice husk about 120 million tonnes, and the rice straw about ten times of the rice production [6]. Indonesia itself produces rice husk about 13 million tonnes annually [7]. When the rice husk was burned until it became a white powder called white rice husk ash, the random of the ash was 22-29 %[8] and the content of silica about 87-97% [9]. The related finding was also reported that the temperature controlled burning at 800°C along 4 hours of rice husks taken from Tabanan Regency of Bali Province Indonesia produced about 20.6% amorphous silica with purity of 99% [10]. Thus, there is a high potency of high purity amorphous silica powder from the rice biomasses.

The high potency of high purity amorphous silica powder from the high siliceous tropical plants especially the rice biomasses causes today the development of the biosilica based advanced materials taken into account intensively and a comprehensive literature review on that is needed for future looking of the competitive beneficial direction on researches and developments. This paper described the role of paddy’s plantation for reserving silica powder unexpensive and environment-friendly, to explain the current developing of advanced materials from the high siliceous rice plant biomasses, to propose a scheme of value addition of paddy’s biomasses for sustainable rice agriculture development. A comprehensive literature review through meta analysis on articles published in last few decades was conducted.

2. Discussion

2.1. The role of rice agriculture for providing high purity silica powder
Paddy’s plants are one of the 15 tropical plants containing rich of silicon [5]. The rice plant biomasses, namely its straw and husk, containing siliceous cellulose and lignocellulose, when it burned, it produced ashes with high content of silica. The high abundance of paddy’s biomasses is supported by the increase of the rice need by Indonesian people that pushed people to open new rice field to produce more rice because almost Indonesian people eat rice. However, the rice biomasses, such as straw and husk, have been yet added their value optimally. For instance, the rice husk was only burned by the rice farmers or it used as biofuel for brick burning and as a raw material for organic fertilizer.

The use of rice straw and husk to produce high purity biosilica powder can add the economic value of the biomasses. Every tonne of rice husk can produce high purity silica powder about 200 kgs or every 5 tonnes of rice husk can produce 1 tonne of silica powder, where its price at USA was USD 500/tonne and in Europe at USD 927/tonne [1]. If it is assumed that the cost production is about 40% from the market price, the added value of the silica powder production from the paddy’s biomasses is about USD 300/tonne. Thus the paddy’s farmers can gain more income and they will retain the rice field from land conversion and the the paddy agriculture can develop sustainably.

It is not only a simpler process in preparing and purifying silica powder from the ashes of rice husks and straws but also it need much lower energy than the preparation and purification processes of silica powder from rocky quartz deposit or quartz sand. The biosilica powder production does not need a lot energy for stone breaking and milling. It is not need also a lot of water and chemicals for purification processes. The biosilica from rice husk ash has very high purity about 87-97% w/w[9] with impurities of oxides K₂O, Na₂O and Fe₂O₃ that those are easily dissolved in dilute mineral acid solutions to become a reactive amorphous silica powder with purity up to 99 % w/w [11]. If the burning at lower temperatures is, for instance at 400°C, a black silica powder consisting mainly black carbon ash and silica is produced, where the black silica powder of rice husk was converted into cubic silicon carbide nanosize powders [10]. Moreover, the burning of those paddy’s biomasses produce heat energy about 3,600 kcal/kg comparing to the burning of coal producing 6,000 kcal/kg [12]. For instance, the villagers used the rice husk for brick or clayware burning and todays it used for heating a boiler in a turbine of an electric generator. The excess smoke of the burning rice husks can be collected through a distillation process to get a liquid smoke. The burning of 1 kg of dried rice husk produced about 810 mL liquid smoke containing volatile compounds such as aldehydes, acids and
phenols that those can be used as preservatives [13]. Figure 1 shows four usefullneses of rice husk and straw producing white purely silica powder, carbonized black silica powder, heat energy and liquid smoke.

![Diagram of rice husk and straw uses](image)

**Figure 1.** The usefullnes of the burning of rice husks and straws

### 2.2. Development of Advanced Materials from Biosilica

The development of rice biomass ash biosilica based advanced inorganic materials are reviewed in terms of two raw materials namely black biosilica and white biosilica powder as well as their production processes of both kinds of biosilica and their application for producing prospective industrial materials. The black biosilica powder was produced by burning rice biomasses at a controlled temperature 400°C and the white biosilica powder was prepared by burning the biomasses at temperature about 800-1000°C [10]. Both powders were removed their impurities namely metall oxides such as K₂O, Na₂O, MgO, CaO, and Fe₂O₃ by washing the powders using dilute mineral acid solutions [10]. The black biosilica based advanced materials discussed further were focused on silicon carbide, silica-carbon nanocomposite, and their application. Meanwhile, the white biosilica based advanced materials discussed furthermore are ultrafine reactive amorphous silica, nanosilica, and their application.

A research on developing of advanced materials from the carbonized rice husk ash called black biosilica for synthesizing silicon carbide was reported [10]. The research showed that controlled heating under vacuum at temperature of 1500°C along 4 hours, the rice husk ash black silica was completely converted into nanosize cubic silicon carbide (β-SiC) powder[10]. This preparative method is relatively simpler and more unexpensive than the Acheson process that used quarzt and coal under argon at heating a temperature above 2000°C. Furthermore, the β-SiC powder was reacted with aluminium metal powder in form of pellets under vacuum at a temperature range of 1000-1500°C along 4 hours [14]. The series of reaction produced a superlight material of aluminium silicon carbide Al₄SiC₄ [14]. The compound of Al₄SiC₄ overcame the formation of aluminium carbide Al₃C₃ which its existance on aluminium alloy could promote the formation of the easily burning methane gas. Thus the aluminium silicon carbide is more pavourable than the aluminium-carbon alloy as a superlight material for aircrafts. The finding of the simple preparation process of the nanosize cubic silicon carbide powder from black rice husk ash silica powder contributed to solve the problem of providing unexpensive and environment-friendly silicon carbide powder for industrial purposes. Moreover, the black biosilica was successfully converted into a reactive silica-carbon nanocomposite powder in a
simple way [15]. A forming of composite matrix between carbon and silica has a prospective uses as reinforcer because of its ability to enhance bulkily the microstructure of a target materials, for instance, it can hold tighting together the filler and matrix in the cellulose fiber – resin matrix system. The use of silica-carbon nanocomposite as reinforcer material for producing a synthetic wood from non-wood lignocellulose fiber was proofed to improve significantly the mechanical properties of resulted synthetic wood comparing with the synthetic wood without using the silica-carbon nanocomposite [15]. These findings may contribute to develope bio-inorganic material based on non-metallic matrix composites.

White biosilica powder from paddy’s agriculture wastes was taken into attention in terms of the development of preparation and characterization methods and its industrial application. The pyrolysis methods of rice husks and straws for producing a reactive biosilica powder, its chemical composition analysis, its purification and its characterization were reported by a lot of researchers [16] [17] [18] [19] [20] [21] [22] [23] [24] [25] since the last two decades. Some studies on directly applying of the reactive amorphous biosilica powder were reported for absorbing gases[26] [27] [28] [29] [30]; for absorbing liquid or solution [27] [31] [32]; as a mixing component in a concrete or mortar [33] [34] [35] [36] [37] [38] [39]; as a precursor [40]; as a ceramic component [41]; and as soil stabilisator [42]. Some researches in improving the rice husk ash biosilica were reported namely, as ultrafine amorphous reactive biosilica powder [43] [44]; as coloidal/gel silica [45]; as meso/nanoporous silica [31] [46] [47]; as nanosilica powder [48] [49]; as glass/membrane silica [50] [51]; for synthesizing zeolites or zeolite-like materials and their application[52-58]; for synthesizing silicon carbide based materials and their applications [10] [59] [60] [61] [62]; for synthesizing silica based composites and their applications [15] [63] [64] [65] [66]. An ultrafine amorphous silica [67] was used as a part composition of cementious binder which reported, was applied for making quake resistant building bricks [68]. The ultrafine amorphous biosilica was also implemented for making calcium silicofosfate having Si-O-P ternary bonding for teeth and bone restorative materials [69].

Structure engineering on the biosilica, namely amorphization and particle size reduction, causes the biosilica powder more porous and reactive. It can take important role in developing inorganic solid state advanced materials. Hence the change of the structure and particle size of the materials can shift their properties. For instance, the biosilica powder with particles in nanosize has distinctive properties comparing to that having particle size in nanometer. Thus, a brief review on the developing of methods and their target of methods for advancing the biosilica based materials is also reported. In term of developing preparation routes, identification and characterization, some articles were reported by some researchers [16] [17] [18] [19] [20] [21] [28] [31] [43] [44] [45] [46] [47] [48] [49] [50] [51]. Some studies were also conducted in order to develop the biosilica based advanced materials and their industrial applications [28] [31] [49] [50] [51] [52] [53] [54] [55] [56] [57] [58] [59] [60] [70] [71].

2.3. A proposed scheme of sustainable development on rice agriculture

Some issues todayes have been faced by paddy’s farmers, especially in Bali Island namely (1) the high production costs including the treating of rice field, planting, weeding, fertilizing, pest avoiding, and harvesting, (2) the increase of fertilizers and pesticides, (3) the low income of the farmers because of the difference between the harvesting grain rice price and the total production costs is so small, (3) the lack of farmers young generation interesting in working at rice field, and (4) the lack of rice field land because of massively land conversion. Those problems treat the retaining the rice agriculture and its “Subak” culture, where Subak is a famous rice farmer organization, thus the sustainable development on providing food for our country is also treated.

A key factor is proposed to solve those faced paddy’s farmer problems, namely a scheme of adding value of rice husks and straws that those todays as side products or called paddy’s agriculture wastes. The proposed scheme focusses on the post harvesting process at a milling instalation and its surrounding area. As seen on Figure 2, the proposed scheme can be described as follows. Firstly, a milling machine will converted the dried milling husked rice grains into unhusked rice grains and rice husks. The rice husks are used for heating resources of the drying maschines by controlled burning
them, their heat is used for drying the wet rice grains. The resulted black ashes can be converted into white rice husk ashes by further burning and its excess heating can be also used for drying process. The black rice husk ashes can be used also for producing silicon carbide powders or silica-carbon nanocomposite powders. The white rice husk ashes can be used for generating further advanced materials such as nanosilica, zeolites, silica fumed, and soon. The excess of rice husk as well as rice straws can be used for providing linocellulosic fibers. The fibers can be used further for synthesing wood-like materials by combining them with silica-carbon nanocomposites. The excess of smokes at the burning processes of rice husk to become black ashes as well as the burning of black rice husk ashes into white ashes can be distillated for producing a liquid smoke containing active compounds for food preservative purposes. The proposed scheme is believed to give impacts in increasing the farmers income and retaining the rice field as well as irrigation system and its Balinese traditional farmer organization “Subak”. Thus the sustainable development in rice agriculture will come true.

![Diagram of value adding for developing paddy’s agriculture sustainably](image)

**Figure 2.** A scheme of value adding for developing paddy’s agriculture sustainably

### 3. Conclusion

Silicon chemistry takes important role for adding values of the rice biomasses namely rice husk and straws by converting them into black as well as white ashes containing rich silica and their generative products such as nanosilica powders, silica-carbon nanocomposite and liquid smoke. The rice straws and husks can be also converted into linocellulosic fibers which can be combined with the silica-carbon nanocomposite and other components such as resin and catalyst to produce a synthetic wood.
The added values can be predicted to enhance the farmers income significantly, thus the paddy’s agriculture can be developed sustainably.

Acknowledgement
Direktorat Riset dan Pemberdayaan Masyarakat, Direktorat Jenderal Penguatan Riset dan Pengembangan, Kementerian Riset, Teknologi dan Pendidikan Tinggi is acknowledged for the Competitive National Strategic Research Grant Year 2016 with Grant Number of 67/UN48.16/LT/2016.

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