

RESEARCH ARTICLE

COMPREHENSIVE EVALUATION OF AERATED SOAKING FOR PADDY PARBOILING IN AN ECO-FRIENDLY MANNER

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ABSTRACT

Aerated soaking of paddy is a simple novel technique to utilize water effectively. Therefore, automated water circulation was maintained in the aerated soaking systems using a motor and timer. The timer was set with 70 minutes on-time and 20 minutes off-time. Hence, aerated soaking systems with operating cycles of 70 minutes on-time and 20 minutes off-time were developed based on dissolved oxygen profile in soaking water. The quality parameters of soaking water and rice were analyzed and compared with the conventional soaking process. In addition, moisture absorption pattern was also studied in aerated soaking systems and compared with the conventional soaking system. Results revealed that the aerated soaking of paddy improved hydration rate and reduced soaking time with a considerable reduction in effluent quality in terms of BOD. The moisture contents of conventional soaking, submerged aerated soaking and exposed aerated soaking were $27.84 \pm 0.01\%$, $30.41 \pm 0.01\%$ and $31.48 \pm 0.01\%$ respectively after 24 hours of soaking. The BOD values of conventional soaking, submerged aerated soaking and exposed aerated soaking were 1575 mg/l, 600 mg/l and 472 mg/l respectively after the end of soaking. The higher DO resulted in the germination of paddy grain which in turn reduced the head rice yield. The values of pH, total dissolved solids, total solids and electrical conductivity of conventional soaking were highly different compared to submerged and exposed aerated soaking systems. The values of head rice percentage (HR- $79.15 \pm 1.15\%$) and broken rice percentage (BR- $20.84 \pm 1.15\%$) of conventional soaking were almost similar to submerged aerated soaking (HR- $79.51 \pm 1.62\%$ and BR- $20.49 \pm 1.63\%$), but remarkably different from exposed aerated soaking (HR- $60.74 \pm 2.00\%$ and BR- $39.25 \pm 1.99\%$). The use of a submerged aerated system yielded a positive outcome related to hydration rate, reduction in terms of BOD (975 mg/l) value with reasonable milling yield profile in terms of head rice percentage. Hence, the system of submerged aerated soaking can be considered as a viable initiative for an eco-friendly parboiling process.

Keywords: Aeration, Cold-water, Evaluation, Paddy parboiling, Submerged aerated soaking.

INTRODUCTION

Rice (*Oryza sativa*) is one of the world's three most important edible starchy cereal crops. It plays a vital role in meeting global food demands. Approximately, half of the world's population consumes rice as a primary source of nutrition and it contributes 20% of the calories (Kubo and Purevdorj 2004). Consumption of rice increases with population growth. A substantial increase in the population is expected in the 21st century (Kubo and Purevdorj 2004). Moreover, rice is the staple food grain in Sri Lanka with an annual per capita intake of 108.6 kg (Kumari *et al.* 2014a). Rough rice is processed in two

forms, raw rice and parboiled rice. Parboiled rice is a hydrothermally treated rice to tune physiochemical properties for better consumption (Itoh *et al.* 1985). However, parboiled rice accounts for around 55% of total rice consumption in Sri Lanka (Kumari *et al.* 2014a) and it contributes to nearly 50% of the energy and 40% of the protein in the daily diet of people in Sri Lanka (Sartaj and Suraweera 2005).

The method of parboiling consists of three stages such as soaking, steaming and drying (Igathinathane *et al.* 2005; Kannan *et al.* 2012; Kumari *et al.* 2014b). The main aim of soaking is to facilitate quick gelatinization of

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the paddy grains and to reduce energy consumption during steaming. The grain moisture content should be increased to at least 30% (wb) to have the perfect steaming process of parboiling (Kannan 2015; Kumari *et al.* 2014a; Wimberly 1983). For different grains, there are three soaking methods in use; cold soaking, hot soaking and vacuum soaking (Kumari *et al.* 2014a). The rate of moisture absorption is largely determined by the moisture gradient, environmental conditions and grain properties (Thakur and Gupta 2006).

The most common practice is soaking paddy in stagnant cold water for 36 - 72 hours at room temperature. Because of the long duration of the cold soaking method, the microorganisms consume all of the dissolved oxygen in the soaking water and fermentation of starch, resulting in anaerobic conditions (Kumari *et al.* 2014a). This results in an odor in both the soaking water and the soaked paddy. To avoid these issues, it is a common practice to change the soaking water at regular interval 10 - 12 hours (Rathnayake *et al.* 2010). For the manufacturing of parboiled rice, the soaking process uses a large volume of water and it is around 1.3 times the weight of paddy (Kannan 2015; Wimberly 1983). The volume of wastewater generated from the parboiling site is 0.4 to 0.52 l/kg of paddy processed. Wastewater contains a high concentration of organic and inorganic substances causing significant polluting effects (Sayanthan and Thusyanthy, 2018). In Sri Lanka, small and semi-modern mills are with higher production costs and limited milling output, resulting in low profitability. As a result, such millers commonly release wastewater into the environment without any treatment (Kumari *et al.* 2014a). The continual discharge of effluent into the environment causes several environmental problems (Thushyanthy *et al.* 2016). Moreover, effluent should be treated to come into the permissible level before disposal. Discharging effluent indiscriminately into the environment can make soil pollution, water pollution and air pollution by releasing noxious gases (Senanayake *et al.* 2001).

Hence, there is a need to modify the commonly used soaking process to solve such

environmental consequences. Therefore, a simple aerated soaking system is considered to be helpful to reduce the microbial population, increase the water usage efficiency, reduce the oxygen demand, reduce effluent quantity and strength in terms of Biological Oxygen Demand (BOD) and increase the milling yield (head rice percentage) in an eco-friendly manner. It further created a piece of new knowledge about Dissolved Oxygen (DO) dynamics in soaking water during the simple aeration cycle of the aerated soaking system. As there are limited research works carried out on aerated soaking of paddy, this novel strategy and its investigations are helpful to propose eco-friendly soaking systems for paddy parboiling. Hence, this study was set to investigate the effect of submerged and exposed aerated soaking systems on effluent quality, paddy hydration and milling yield with an intention of proposing an eco-friendly strategy for the paddy parboiling process.

MATERIALS AND METHODS

The experiment was conducted at the Department of Agricultural Engineering, Faculty of Agriculture, University of Jaffna, Kilinochchi.

Long paddy grain variety Bg 251 was selected for this study. Newly harvested dried paddy (moisture content - 13.4% wb) was obtained from Paddy Research Institute, Paranthan, Kilinochchi. Impurities and foreign materials were removed from the paddy sample before the experiment.

Simple aerated soaking system and its design

Three PVC pipes of 1.5 m height and 100 mm diameter were used as the testing soaking tanks to represent conventional soaking (CS), exposed aerated soaking (EAS) and submerged aerated soaking (SAS) as shown in Fig. 1. A water pressure pump (ARPICO 90W 230V/50Hz) was used to circulate the water through the PVC column. A 25 mm PVC pipe was used to circulate the water in the aeration unit. The pump was fixed with the SAS column and EAS column. A showerhead with fine holes of a diameter less

effluent characteristics and milling yield analysis. The instrumentation and measurement procedures are described below.

Moisture content

The standard oven-dry method was used to determine the moisture content of the paddy. Accurately measured 5 g of sample was kept in the oven overnight at 105 °C. After drying, the final weight was measured (AOAC, 2000). Moisture content was calculated by the Eqn 1 (Kannan *et al.* 2012).

Aspect ratio

Length (mm) and width (mm) of randomly selected paddy samples were measured using vernier calliper with a reading error of 0.01 mm (Model: KANON E-PITA 20 Digital).

The aspect ratio was calculated by the Eqn 2 (Nadvornikova *et al.* 2018; Varnamkhasti *et al.* 2008).

True density

It was determined by the toluene displacement method (Ravi and Venkatachalam 2014). Since paddy absorbs toluene more slowly than water, toluene (C₇H₈) was used instead of water. The preweighed paddy sample was placed into the known volume of toluene in a measuring cylinder. Toluene displacement was noted as volume (ml).

Bulk density

It was determined using the mass/volume relationship (Ravi and Venkatachalam 2014). Therefore, paddy was filled into the empty container of predetermined volume and

$$\% \text{ Moisture content (wb)} = \frac{\text{Initial weight (g)} - \text{Final weight (g)}}{\text{Initial weight (g)}} \times 100 \quad (\text{Eqn 1})$$

$$\text{Aspect ratio} = \frac{\text{Width of paddy (mm)}}{\text{Length of paddy (mm)}} \quad (\text{Eqn 2})$$

$$\text{Porosity (\%)} = 1 - \frac{\text{Bulk density}}{\text{True density}} \times 100 \quad (\text{Eqn 3})$$

$$\text{Elongation percentage} = \frac{\text{Final length (mm)} - \text{Initial length (mm)}}{\text{Initial length (mm)}} \times 100 \quad (\text{Eqn 4})$$

$$\text{Germination percentage} = \frac{\text{Number of seed germinated}}{\text{Total number of seeds taken}} \times 100 \quad (\text{Eqn 5})$$

$$\text{Total Solids (g/l)} = \frac{\text{Final weight of beaker (g)} - \text{Initial weight of beaker (g)}}{10 \text{ ml}} \times 1000 \text{ ml} \quad (\text{Eqn 6})$$

$$\text{Milling recovery (\%)} = \frac{\text{Weight of milled rice (g)}}{\text{Weight of paddy sample used (g)}} \times 100 \quad (\text{Eqn 7})$$

$$\text{Head rice (\%)} = \frac{\text{Head rice weight (g)}}{\text{Sample weight (g)}} \times 100 \quad (\text{Eqn 8})$$

$$\text{Broken rice (\%)} = \frac{\text{Broken rice weight (g)}}{\text{Sample weight (g)}} \times 100 \quad (\text{Eqn 9})$$

$$\text{Heat damaged grains (\%)} = \frac{\text{Weight of heat damaged rice (g)}}{\text{Sample weight (g)}} \times 100 \quad (\text{Eqn 10})$$

$$\text{Weightbelly (\%)} = \frac{\text{Weight of whitebelly (g)}}{\text{Sample weight (g)}} \times 100 \quad (\text{Eqn 11})$$

Head rice percentage

Head rice percentage was done using Length Grader (Model: Grainman length grader 68). Polished rice of 300 g was kept in the grader. The time (50 Sec) and speed (45 rpm) were set before running the grader. Analysis was done two times to increase the accuracy. The Eqn 8 was used to calculate the percentage of head rice (Thupeeban and Kannan 2017).

Broken rice percentage

Broken rice percentage was measured using Length Grader (Model: Grainman length grader 68). At that same time, head rice and broken rice were separated. The Eqn 9 was used to calculate the broken rice percentage (Thupeeban and Kannan 2017).

Heat-damaged grains percentage

Paddy sample of 100 g was measured and hand separation was done based on observation of grains. As at least 10% of its surface area has been burnt, it was identified as heat-damaged grains (Mamadou *et al.* 2011). The Eqn 10 was used to calculate the heat damaged percentage.

Whitebelly percentage

Rice contains an internal white region that is referred to as whitebelly (Xi *et al.*, 2014). Paddy sample of 100 g was measured and hand separation was done. The Eqn 11 was used to calculate the whitebelly percentage (Thupeeban and Kannan 2017).

Whiteness value

The whiteness value of milled rice samples were measured by KETT Digital Whiteness Meter (Model: C-300-3). It was calibrated with ceramic to a value, 88.5. After that, paddy grains were placed. The displaced value was recorded as a whiteness value of samples placed.

RESULTS AND DISCUSSIONS

Physical properties of paddy

The initial moisture content of paddy was recorded as 13.4% (wb). According to the International Rice Research Institute (IRRI), normally after harvesting, dried paddy contains a moisture content lesser than 14%

(wb) (Imoudu and Olufayo, 1999). Furthermore, the length (mm) and width (mm) of paddy grains were 7.82 ± 0.01 and 2.64 ± 0.06 respectively. It belongs to long grain under size classification and medium grain under shape classification (Chemetova 2013). The aspect ratio was calculated as 0.33. The porosity of paddy grain was calculated as $48.98 \pm 3.70\%$. Furthermore, bulk density and true density of long paddy grain are $0.59 \pm 0.02 \text{ g/cm}^3$ and $1.16 \pm 0.08 \text{ g/cm}^3$ respectively. However, researchers reported porosity, bulk density and true density of paddy grains were to be 46 - 54%, 0.563 - 0.642 g/ml and 1.182 g/ml respectively (Bhattacharya *et al.* 1972). The information obtained in this section was highly useful to make a better scientific analysis of aerated soaking of paddy parboiling.

Moisture content change

Fig. 2 shows the relationship between the moisture content of paddy grains and soaking time of three different soaking methods. It is obvious from Fig. 2 that during the first 12 hours of soaking, a weighty rise in moisture content was observed in three different soaking methods due to the high moisture gradient that existed between paddy grain and soaking water environment (Kannan 2015; Thakur and Gupta 2006). However, moisture content changed very differently after 12 hours of soaking. Moreover, the rapid increase observed in the EAS and SAS compared to CS is due to the water circulation and aeration. Moisture content values for CS, SAS and EAS were $27.84 \pm 0.002\%$, $30.41 \pm 0.007\%$ and $31.48 \pm 0.01\%$ respectively after 24 hours of soaking. Both the aerated soaking systems were stopped after 24 hours due to the moisture content of 30% (wb). However, it took 48 hours to reach 30% (wb) moisture content in CS. This delay is due to the slow migration of moisture into paddy grains (Kannan 2015; Kumari *et al.* 2014a). During 24 - 48 hours, the rate of increasing moisture content was lower than the first 24 hours due to the formation of solid boundary around the paddy grain as the stagnant water prevailed. Moreover, this layer prevents the penetration of the water molecules inside the paddy grain. The same observation was

Faculty of Agriculture was used to soak the paddy grains. Before using water, TS, DO, pH, TDS and EC values were determined. Initial values of pH, DO, EC, TDS and TS of used water were 7.53 ± 0.08 , 7.91 ± 0.04 mg/l, 2470 ± 98.99 μ S/cm, 1088.5 ± 21.92 mg/l and 1.2 ± 0.01 g/l respectively. This piece of information is critical for analyzing changes in these parameters during different soaking methods.

Dissolved Oxygen (DO)

Fig. 5 shows the effect of aeration on DO of three different soaking methods. It is obvious from Fig. 5 that the DO value gradually decreased during the first 6 hours of three soaking methods due to the activation of aerobic microorganisms in the soaking water (Kannan, 2015). They utilized the DO in the water. After that, during 6 - 10 hours, a notable reduction of DO was observed in the soaking water. Researchers reported similar pattern as reported in this study because microbial activities are determinants of the DO and pH of soaking water based on the availability of the organic matter (Kannan 2015; Ramalingam and Raj 1996).

DO values for CS, SAS and EAS were 2.34 ± 0.02 mg/l, 1.85 ± 0.03 mg/l and 1.95 ± 0.04 mg/l respectively after 12 hours of soaking. However, DO changes are very different after 12 hours of soaking in SAS and EAS due to the aeration process. Both aerated soaking systems were stopped after 24 hours of soaking which yielded 30% (wb) moisture content required for effective soaking. Therefore, SAS and EAS systems are set with no DO values after 24 hours.

However, it continued for CS up to 48 hours of soaking cycle by which required moisture content of 30% (wb) was obtained and end of the soaking DO reduce to 0.89 ± 0.01 mg/l. It has been reported that soaking water of CS exhibited DO values of 0.9 mg/l (Pradhan and Sahu 2004; Sayanthan and Thusyanthy 2018). A notable rise was observed during 12 to 14 hours of EAS and SAS because after 12 hours of soaking water circulation started. It lead to a rapid DO increase due to atmospheric diffusion.

During 14 to 24 hours of soaking, DO value decreased due to the dynamics of the aerobic microorganisms. The DO values of SAS, EAS and CS were 2.19 ± 0.02 mg/l, 3.15 ± 0.17 mg/l and 2.09 ± 0.01 mg/l respectively after 24 hours of soaking. Both the SAS and EAS yielded higher DO than the CS system. However, the DO value of EAS is higher than the SAS system because of different mechanisms of oxygen addition. In the EAS system oxygen addition is through the atmosphere and paddy column. Hence, its values are always higher than other methods (Kannan 2015). Therefore, the observations made in this study are in line with reported findings.

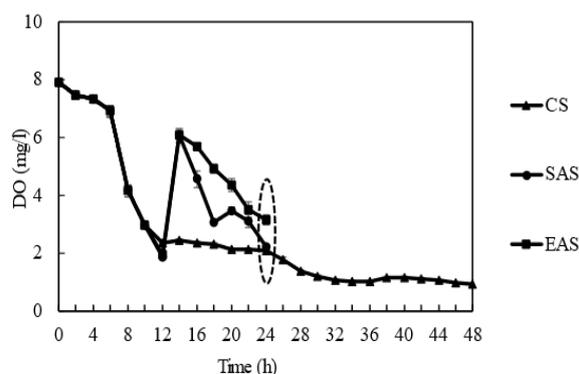


Figure 5: Effect of aeration on DO of three different soaking methods

Biological Oxygen Demand (BOD)

Fig. 6 shows the BOD value of three different soaking methods in mg/l. The values of BOD were 1575 mg/l, 600 mg/l and 472 mg/l for CS, SAS and EAS respectively. It has been reported that the BOD values of CS, SAS and EAS were 950 mg/l, 750 mg/l and 700 mg/l respectively (Kannan 2015). The prominent difference in BOD values has been observed in both aerated soaking systems compared to the CS method. The value of BOD was lower in both SAS and EAS compared to CS due to the artificial aeration provided in aerated soaking systems. Moreover, in EAS and SAS processes, DO addition was made by aeration which resulted in lower BOD values. The reason for the high BOD value in CS is the hydrolysis of organic materials presented in paddy grains.

processes increased with the soaking period, but the increase was not gradual. EC of all three different soaking methods gradually increased up to 10 hours of soaking. However, EC changes are very different after 12 hours of soaking in SAS and EAS compared to CS due to the influence of aeration on solid dynamics. It was mixing the soluble ions in the soaking water.

The EC values in $\mu\text{S}/\text{cm}$ for CS, SAS and EAS were 2995 ± 21.21 , 2940 ± 56.56 and 2790 ± 42.42 respectively after 12 hours of soaking. However, EC of the CS water is gradual because of the reduction in the concentration gradient of the soluble ions in the soaking water. After 12 hours, a notable rise was observed in SAS and EAS. The values of EC were $3680 \pm 56.56 \mu\text{S}/\text{cm}$ and $3165 \pm 21.21 \mu\text{S}/\text{cm}$ for after 14 hours of soaking of SAS and EAS respectively. Therefore, the circulation of soaking water increased the ability of soluble ions to be leached from paddy grain. This situation increases the soluble solid dynamics (Kannan 2015).

The EC value was $4005 \pm 7.07 \mu\text{S}/\text{cm}$ after 48 hours for CS. During the period from 12 hours of soaking to 24 hours of soaking, EAS and SAS showed an increasing trend in EC compared to CS. The highest EC value observed for the SAS method was due to high solute concentration due to the leaching of soluble solids.

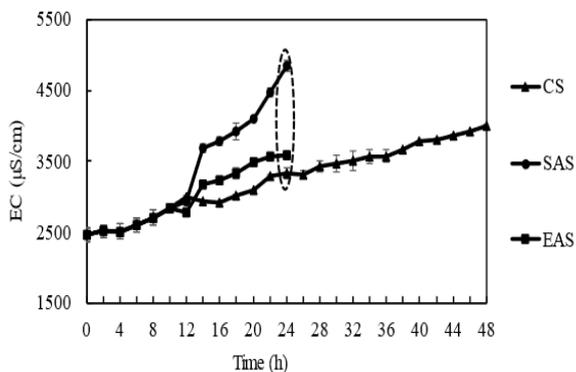


Figure 8: Effect of aeration on EC of three different soaking methods

This highest suction force in submerged aeration resulted in higher leaching rates. Furthermore, the degree of suction force is low for exposed aeration compared to submerged aeration system. Therefore, the EC of the submerged aeration system is high compared to exposed aeration system. A similar pattern has been observed for TDS concentration in three different soaking systems of this experiment. It has been reported that the TDS could be estimated from electrical conductivity (EC). The linear relationship between TDS and EC can be stated as $\text{TDS (mg/l)} = k_e \times \text{EC } (\mu\text{S}/\text{cm})$. (k_e is a constant of proportionality) (Taylor *et al.* 2018). Therefore, the observation made in this study matches with reported findings.

pH

Fig. 9 shows the effect of aeration on the pH of the three different soaking methods. It is obvious from Fig. 9 that the pH value gradually decreased during the first 6 hours of soaking for all three soaking methods due to the activation of microbial dynamics between soaking water and paddy grains. After that, during 6 to 8 hours of soaking, an astonishing reduction in pH was observed in the soaking water due to the proliferation of microbial colonies, resulting in the formation of phenolic compounds in the soaking water (Kannan 2015; Senanayake *et al.* 2001). However, during 8 to 12 hours of soaking, again gradual decrease was observed due to the microbial activity. The pH values for CS, SAS and EAS were 6.51 ± 0.06 , 6.39 ± 0.02 and 6.32 ± 0.01 respectively after 12 hours of soaking.

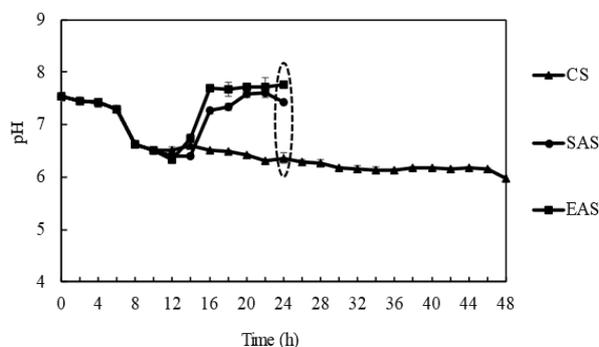


Figure 9: Effect of aeration on pH of three different soaking methods

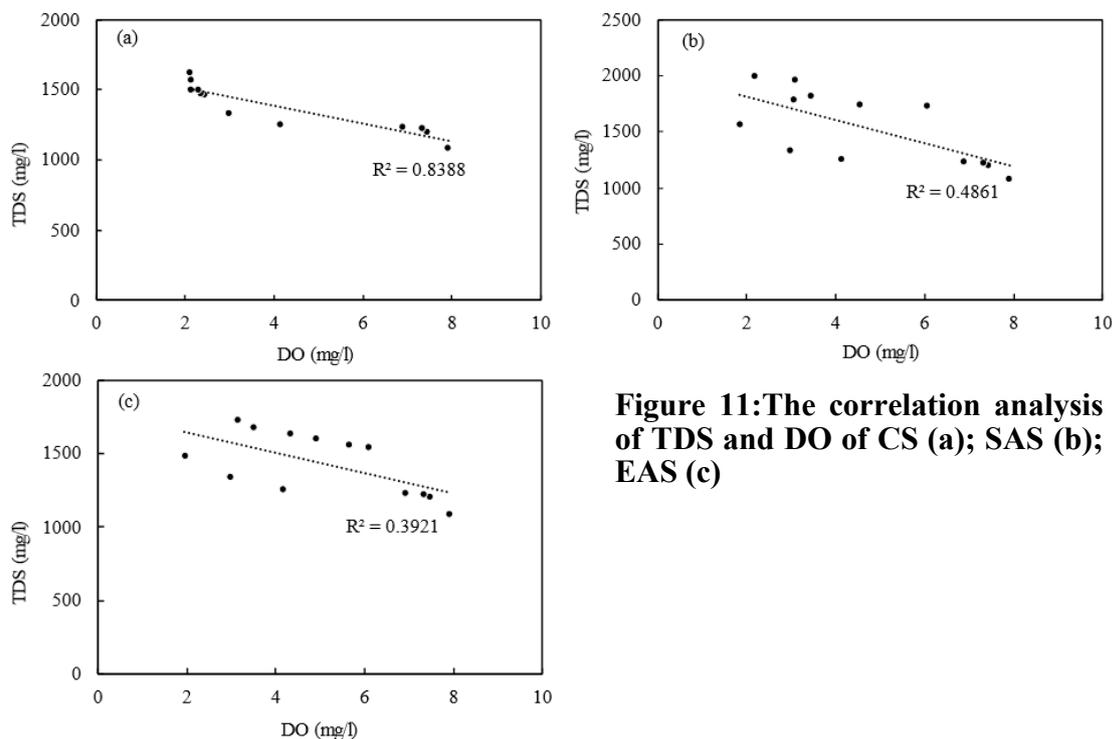


Figure 11: The correlation analysis of TDS and DO of CS (a); SAS (b); EAS (c)

relationship between TDS and DO for SAS and EAS system is not well correlated as of the influence given to DO profile of soaking water by deliberate aeration which made different patterns of soluble solids degradation. The R^2 value of SAS and EAS is 0.4861 and 0.3921 respectively, which show a weak relationship between TDS and DO. It has been reported that the TDS concentration of soaking water is influenced by DO concentration during soaking. The same observations were obtained in water eutrophication (Muigai *et al.* 2010).

The relationship between pH and DO of different soaking methods

The relationship between pH and DO (mg/l) of three different soaking methods, CS, SAS and EAS are shown in Fig. 12. The relationship between pH and DO is positively correlated. The CS system exhibited a direct relationship between pH and DO. The pH in the soaking system was low as DO concentration was low. This scenario can be explained by considering the microbial population and organic substances degradation pattern with DO concentration in soaking water. At high DO concentration, the

aerobic microbes utilized dissolved oxygen. Therefore, the system is exposed to the anaerobic condition. Due to this anaerobic condition, fermentation of starch occurred, resulting in the formation of acid substances like volatile acids produced by anaerobic microbes in the soaking water environment (Kannan 2015).

Due to this microbial activity, pH was reduced when DO concentration was reduced. However, the relationship between DO and pH for SAS and EAS system is not well correlated as of the influence given to DO profile of soaking water by deliberate aeration which made different patterns of the microbial population. The soaking water environment was kept above 1 mg/l of dissolved oxygen value. The increasing trend in pH of soaking water with DO has been reported during paddy soaking (Kumari *et al.* 2014a).

The R^2 values of SAS and EAS are 0.0744 and 0.1255 respectively, which show the weak relationship between pH and DO. It has been reported that the pH of soaking water was highly influenced by DO concentration during soaking. Researchers reported the pH

activities of paddy, resulting in germination. Due to this, the head rice percentage of EAS was reported to be low than the other two methods. The values of head rice percentage of CS, SAS and EAS were $79.15 \pm 1.15\%$, $79.51 \pm 1.62\%$ and $60.74 \pm 2.00\%$ respectively.

Furthermore, the broken rice percentage of EAS increased due to paddy germination. Germination of paddy reduced the milling yield percentage (Han *et al.*, 2016). The values of broken rice percentage of CS, SAS and EAS were $20.84 \pm 1.15\%$, $20.48 \pm 1.16\%$ and $39.25 \pm 1.99\%$ respectively. Broken rice

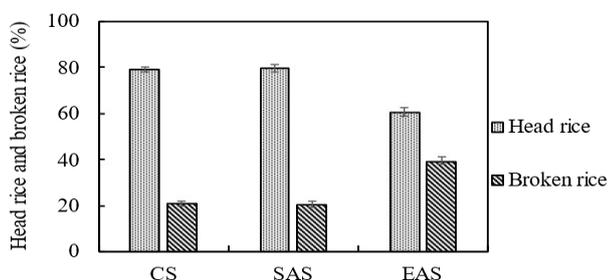


Figure 14: Head rice and broken rice percentage of different soaking methods

percentage goes down as head rice percentage increases.

Regression analysis of white bellies, heat-damaged grains and whiteness value of parboiled rice

Fig. 15 (a, b and c) shows the whitebelly, whiteness value and heat damaged-grains of three different soakings of parboiled paddy grains. Fig. 15 (a) indicates the whitebelly percentages of CS, SAS and EAS $1.16 \pm 0.10\%$, $1.32 \pm 0.02\%$ and $1.33 \pm 0.05\%$ respectively. Fig. 15 (b) shows the whiteness value percentages of CS, SAS and EAS were 20.16 ± 0.05 , 20.76 ± 0.37 and 20.83 ± 0.30 . Fig. 15 (c) displays the heat-damaged grains percentages of CS, SAS and EAS were 0.9 ± 0.26 , 1.36 ± 0.04 and 1.65 ± 0.23 . The long time it took to reach the moisture content of 30% (wb) in the CS resulted in the uniform moisture migration to the centre of the paddy grains, which in turn turned into a lower whitebelly percentage. However, the quick moisture absorption in SAS and EAS systems left the centre of the paddy grain not hydrated with water, which produced a higher whitebelly percentage (Buggenhout *et al.*,

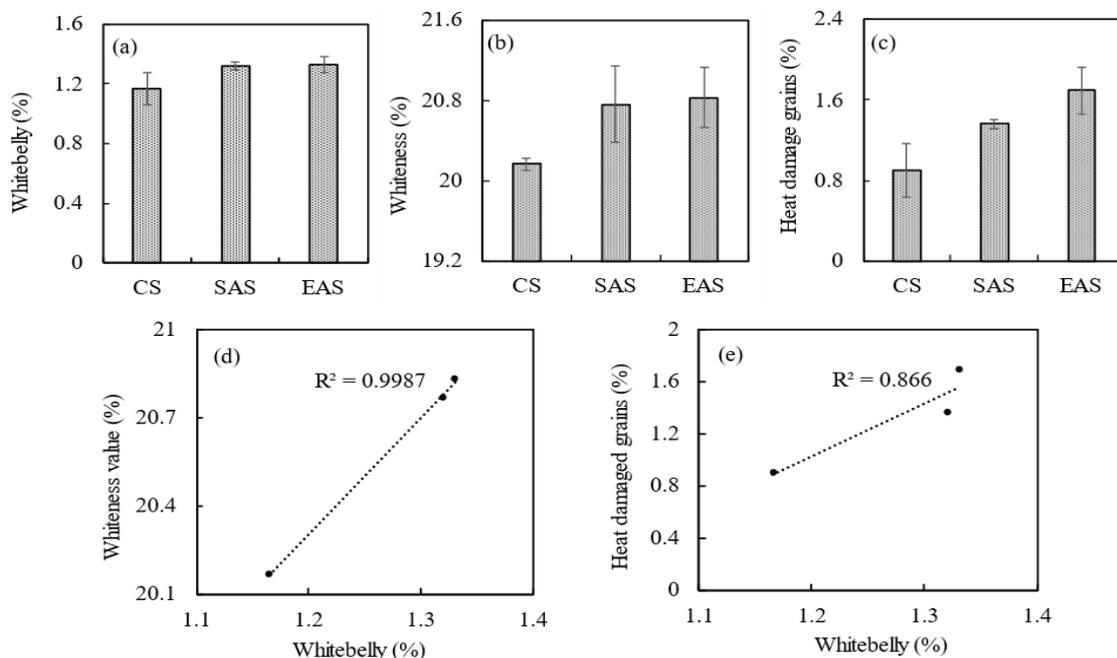


Figure 15: The scenario of whitebelly (a); whiteness value (b); and heat-damaged grains (c); and regression analysis of whiteness value and whitebelly (d); and heat-damaged grains and whitebelly (e) of three different soaking methods.

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