

# Characteristic changes in malt, wort and beer produced from different Nigerian rice varieties as influenced by varying malting conditions

Chigozie E Ofoedu<sup>Corresp., 1</sup>, Chibugo Q Akosim<sup>1</sup>, Jude O Iwouno<sup>1</sup>, Chioma D Obi<sup>2</sup>, Ivan Shorstkiic<sup>3</sup>, Charles Odilichukwu R Okpala<sup>Corresp., 4</sup>

<sup>1</sup> Department of Food Science and Technology, School of Engineering and Engineering Technology, Federal University of Technology, Owerri, Owerri, Imo, Nigeria

<sup>2</sup> Department of Food Science and Technology, Nnamdi Azikiwe University, Awka, Anambra, Nigeria

<sup>3</sup> Department of Technological Equipment and Life-Support Systems, Kuban State Technological University, Krasnodar, Russian Federation

<sup>4</sup> Department of Functional Food Products Development, Faculty of Biotechnology and Food Science, Wrocław University of Environmental and Life Sciences, Wrocław, Poland

Corresponding Authors: Chigozie E Ofoedu, Charles Odilichukwu R Okpala  
Email address: chigozie.ofoedu@futo.edu.ng, charlesokpala@gmail.com

Characteristic changes in malt, wort and beer from different Nigeria rice varieties (FARO 44, FARO 57, NERICA 7) as influenced by varying malting conditions (steeping duration [18, 24 and 30 h], germination periods [2, 3 and 4 days] and kilning temperatures [50 and 55 °C]), were investigated. Rice (grain) samples were examined by thousand corn weight (TCW), germinative energy (GE), germinative capacity (GC), and degree of steeping (DoS). Rice malt with peak diastatic power (DP), cold water extract (CWE) and hot water extract (HWE), further tested for moisture content (MC), total nitrogen (TN), malt yield (MY), and malting loss (ML) progressed to wort brewing. Wort's pH, total soluble nitrogen (TSN), brix, kolbach index (KI), free amino nitrogen (FAN), dextrose equivalent (DE), original extract (OE), and sugar profile, whereas beer's pH, colour, apparent extract (AE), alcohol by volume (ABV), turbidity, and sensory attributes were determined. Rice grain varied significantly ( $p < 0.05$ ) in TCW, GE, GC and DoS across varieties. Peak DP, CWE and HWE were obtained at FARO 44 [18h steeping, 3days germination, 55°C kilning ( $S_{18}G_3K_{55^\circ}$ )], FARO 57 [30h steeping, 2days germination, 50°C kilning ( $S_{30}G_2K_{50^\circ}$ )] and NERICA 7 [24h steeping, 3days germination, 55°C kilning ( $S_{24}G_3K_{55^\circ}$ )]. Despite wort's pH, TSN, DE, OE as well as beer pH, colour, AE, and turbidity resembling ( $p > 0.05$ ) across varieties, wort's brix, KI, FAN, sugar profile as well as beer's ABV, differed significantly ( $p < 0.05$ ). Sensory attributes of appearance, colour, mouthfeel, and overall acceptability in beer differed noticeably ( $p < 0.05$ ), except for aroma and taste ( $p > 0.05$ ). Overall, the rice beer, though very slightly hazy, represented a pale yellow light lager.

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Chigozie E. Ofoedu<sup>a\*</sup>, Chibugo Q. Akosim<sup>a</sup>, Jude O. Iwouno<sup>a</sup>, Chioma D. Obi<sup>b§</sup>, Ivan Shorstkii<sup>c</sup> and Charles Odilichukwu R. Okpala<sup>d</sup>

<sup>a</sup>Department of Food Science and Technology, School of Engineering and Engineering Technology, Federal University of Technology, Owerri, Imo State, Nigeria.

<sup>b</sup>Department of Food Science and Technology, Nnamdi Azikiwe University, Awka, Anambra State, Nigeria.

<sup>c</sup>Department of Technological Equipment and Life-Support Systems, Kuban State Technological University, Krasnodar, Russian Federation.

<sup>d</sup>Department of Functional Food Products Development, Faculty of Biotechnology and Food Science, Wroclaw University of Environmental and Life Sciences, 50-375 Wroclaw, Poland.

<sup>§</sup>This current work is dedicated to late Chioma D. Obi (Mrs.), who passed away on June 1, 2020.

\*Corresponding authors: [chigozie.ofoedu@futo.edu.ng](mailto:chigozie.ofoedu@futo.edu.ng), (CE Ofoedu); [charlesokpala@gmail.com](mailto:charlesokpala@gmail.com), (COR Okpala)

Running title: Changes in rice malt, wort and beer properties

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# **ABSTRACT**

Characteristic changes in malt, wort and beer from different Nigeria rice varieties (FARO 44, FARO 57, NERICA 7) as influenced by varying malting conditions (steeping duration [18, 24 and 30 h], germination periods [2, 3 and 4 days] and kilning temperatures [50 and 55 °C]), were investigated. Rice (grain) samples were examined by thousand corn weight (TCW), germinative energy (GE), germinative capacity (GC), and degree of steeping (DoS). Rice malt with peak diastatic power (DP), cold water extract (CWE) and hot water extract (HWE), further tested for moisture content (MC), total nitrogen (TN), malt yield (MY), and malting loss (ML) progressed to wort brewing. Wort's pH, total soluble nitrogen (TSN), brix, kolbach index (KI), free amino nitrogen (FAN), dextrose equivalent (DE), original extract (OE), and sugar profile, whereas beer's pH, colour, apparent extract (AE), alcohol by volume (ABV), turbidity, and sensory attributes were determined. Rice grain varied significantly ( $p < 0.05$ ) in TCW, GE, GC and DoS across varieties. Peak DP, CWE and HWE were obtained at FARO 44 [18h steeping, 3days germination, 55°C kilning ( $S_{18}G_3K_{55^\circ}$ )], FARO 57 [30h steeping, 2days germination, 50°C kilning ( $S_{30}G_2K_{50^\circ}$ )] and NERICA 7 [24h steeping, 3days germination, 55°C kilning ( $S_{24}G_3K_{55^\circ}$ )]. Despite wort's pH, TSN, DE, OE as well as beer pH, colour, AE, and turbidity resembling ( $p > 0.05$ ) across varieties, wort's brix, KI, FAN, sugar profile as well as beer's ABV, differed significantly ( $p < 0.05$ ). Sensory attributes of appearance, colour, mouthfeel, and overall acceptability in beer differed noticeably ( $p < 0.05$ ), except for aroma and taste ( $p > 0.05$ ). Overall, the rice beer, though very slightly hazy, represented a pale yellow light lager.

**Keywords:** malting conditions; rice malt; rice beer; rice wort; mashing process

# **1. INTRODUCTION**

Global production of rice (*Oryza sativa*) to meet up with consumer demand is projected to potentially double by 2050 (USDA-ERS, 2019; OECD/FAO, 2019). In Africa, Nigeria leads in rice production (Daoui, 2018) with 2018 rice paddy production record of 6.81 million tonnes (World Data Atlas, Accessed 08 June 2020). The recent curb to imported rice was aimed to allow for increased local production (Russon, 2019). Nigeria imported barley malt until the 1988 ban (Koleoso & Olatunji, 1992), which intensified focus of indigenous breweries on locally produced/commercially thriving cereals like maize, rice, and sorghum. Besides rice, barley is another global cereal that breweries utilize (Contreras-Jimenez *et al.*, 2018, Daneri-Castro, Svensson & Roberts, 2016). Non-temperate countries unable to commercially produce barley, supplement by imports (either malted or unmalted) for their breweries.

Prior to the 1988 Nigeria barley malt importation ban however, various pilot plant and commercial tests had established locally cultivated sorghum malt or grit as brewing candidates compared with existing barley malt brands (Koleoso & Olatunji, 1992). Resembling those of sorghum, malted maize brewing properties could potentially replace the barley malt (Okafor & Aniche, 1980). By assessing malting and brewing potentials, Okafor and Iwouno (1991) reported Nigerian rice varieties as promising substitute for barley in beer production. Odibo, Nwankwo and Agu (2002) reported fermentable extracts from locally cultivated sorghum to keep for a longer time, until required in the brewing process. Whilst Ogbeide (2011) showed sorghum as an adjunct to malted barley in wort production/brewing process, Iwouno and Ojukwu (2012) showed malting quality potential of a Nigerian locally cultivated yellow maize variety. Recently, Ofoedu, Osuji and Ojukwu (2019) reported sugar profile of local rice product/derivate (syrup) resembled that of barley wort.

Malting process involves steeping, germination and kilning, and is crucial in beer production to develop the inactive hydrolytic enzymes present in raw grain (Dewar, Taylor & Berjak, 1997). Steeping enhances grain softening, increases water availability and stimulates germination (Sripriya, Anthony & Chandra, 1997). Mashing facilitates enzymatic degradation of polysaccharides present (in malt), eventually converts to alcohol in fermentation step of beer manufacturing (Gupta, Abu-Ghannam & Gallagher, 2010). Low protein and fat content of rice, instead, assures a slightly higher starch content compared to barley (Narziss & Back, 2012), though with different starch structure, and composition in amylose and amylopectin, as well as a

lower amylolytic activity than barley (Cela et al., 2020). Besides incomplete saccharification in some malted rice during mashing, sufficient protein degradation can breakdown its endosperm especially the cell wall structure, either prior to or simultaneously with starch (saccharification) (Narziss & Back, 2012). As protein degradation appears more challenging in malted rice over barley, the endogenous enzyme facilitates wort production, since during malting the rice attains a higher alpha-amylase production (Ayernor & Hammon, 2000).

Evolved over the years, Nigeria's local rice varieties possess improved qualities that compete with foreign ones. These local varieties increasingly thrive spreading its distribution/reputation to the West African sub region. Further, researchers/processors and local breweries seeing such increases in rice production capacity, have recently began facilitating (rice) product diversification into useful products like syrups (Ofoedu et al., 2020), gluten free beers (Cela et al., 2020), flours, and malts (Osuji, Ofoedu & Ojukwu, 2019). Though rice grits have been used as adjuncts in brewing, the use of rice malt as specialty ingredient or base malt is of growing interest in brewing an all-rice malt beer. As a principal raw material or substrate for brewing, malted rice specifically from locally produced varieties, however, appears not fully utilised. In this context, therefore, the current study was directed to determine the characteristic changes in malt, wort and beer samples from different promising locally available (Nigeria) rice varieties as influenced by varying malting conditions.

## **2. MATERIALS AND METHODS**

### *2.1. Schematic overview of experimental study*

The schematic overview of experimental study, showing the key/major stages from the procurement of rice samples through malting, wort production and beer production to laboratory analyses, is shown in Figure 1. Specifically, this current work was designed to examine some characteristic changes in malt, wort and beer from different locally produced (Nigeria) rice varieties, as influenced by varying malting conditions. This involved experimental variables, namely: steeping durations (18 h, 24 h and 30 h), germination periods (2, 3 and 4 days) and kilning temperatures (50 °C and 55 °C).

### *2.2. Procurement of chemicals, enzymes and rice grains*

Procured from certified sources, all chemicals and reagents (i.e., Copper (II) sulphate pentahydrate ( $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$ ), Potassium sodium tartrate tetrahydrate ( $\text{KNaC}_4\text{H}_4\text{O}_6 \cdot 4\text{H}_2\text{O}$ ),

Calcium hydroxide ( $\text{Ca}(\text{OH})_2$ ), hydrochloric acid ( $\text{HCl}$ ), boric acid ( $\text{H}_3\text{BO}_3$ ), potassium sulphate ( $\text{K}_2\text{SO}_4$ ), sulfuric acid ( $\text{H}_2\text{SO}_4$ ), Trioxonitrate (V) acid ( $\text{HNO}_3$ ), sodium metabisulphite ( $\text{Na}_2\text{S}_2\text{O}_5$ ), Sodium hydroxide ( $\text{NaOH}$ ), Ammonium hydroxide ( $\text{NH}_4\text{OH}$ ), Ninhydrin, Methylene blue indicator, Phenolphthalein indicator, Fehling's solution, Anhydrous D-glucose) were of analytical grade standard.

Commercial exogenous enzymes (namely:  $\alpha$ -amylase and  $\beta$ -amylase) were procured from Nigerian breweries PLC (Awo-Omamma, Imo State, Nigeria). Protease enzyme and isomerised hops used were procured from Department of Applied Microbiology and Brewing, Enugu State University of Science and Technology, Enugu State, Nigeria. Yeast strain (*Saccharomyces pastorianus*) was procured from the Nigerian Breweries PLC (Ama, Enugu State, Nigeria).

Improved rice grains (FARO 44, FARO 57 and NERICA 7) were purchased from National Cereals Research Institute, Amakama, Olokoro Umuahia, Abia State, Nigeria.

### 2.3. Processing of rice samples

#### 2.3.1. Malting of rice

After manual cleaning, the paddy rice of different varieties sorted to remove contaminants/damaged seeds, was winnowed to remove dust. Prior to malting, the rice paddy were disinfected in water containing 0.20 % sodium metabisulphite. The malting process followed method of Kunze (2004) with some modifications. Briefly, rice samples were steeped in water at 20 - 25 °C for 18, 24 and 30 h with alternating steep cycle of 6 h wet-steep period and 30 min air rest. Grains were allowed to germinate, thereafter removed after 2, 3 and 4 days and kilned in hot air oven (Genlab, England, Model M 30 C, S/N 92B060) at temperatures between 50 – 55 °C for about 22 – 24 h. Kilned samples were manually de-rooted by rubbing off with hand, winnowed to remove the rootlets/dust and milled to produce the rice grist.

#### 2.3.2 Production of rice malt wort

The flow diagram of rice malt wort production, presented in Figure 2, slightly modified from the previously studies (Nwanekezi, Osuji & Onyeneke, 2007; Ofoedu et al., 2019; Iwouno, Ofoedu, Ugwuegbulam & Nwokoro, 2019), which involved a three-step decoction mashing process. Rice malt grist (~ 2 kg) was dissolved in clean filtered potable water (8 L) previously

made to a pH of 11.0 using  $\text{Ca}(\text{OH})_2$  solution. The entire mash temperature was raised to 35 – 40 °C to acidulate the mash followed by addition of 1 mL of protease for proteolysis to take place, with temperature maintained for 30 min at gentle stirring (acid rest). First decoction involved transferring one-third of the mash to a mash kettle and heated to 70°C. Heated mash was transferred back to the remaining two-third mash, with entire temperature raised to 50 – 55°C, followed by addition of  $\alpha$ -amylase (0.8 mL) and subsequently allowed to rest for 30 min (protein rest). Second decoction involved one-third of the mash was further heated in the mash kettle (3 - 5 min) until temperature of 85°C was reached, then transferred to the remaining two-third thin mash, raising the temperature to ~ 67°C and the mash gelatinized, which was allowed to rest for 30 min after addition of  $\alpha$ -amylase (0.8 mL). Following liquefaction, a third decoction involved raising temperature to 100°C, wherein boiled mash was added to the remaining mash, which moderated the entire temperature to about 72 – 75°C. Mash rested again for ~30 min after addition of  $\beta$ -amylase (0.8 mL) prior to saccharification. To ascertain complete degradation of starch, the Iodine test was carried out. To denature the enzymes prior to wort lautering, mashing-out was carried out. Spent grains were sparged with 1000 mL of hot sparge water at 80 °C to obtain the entire wort from the mashing operation, before wort was concentrated.

### 2.3.3. Production of rice malt beer

Adopting the Japanese rice lager production process, however, the rice malt beer in this study was produced according to the method described by Briggs *et al.* (2004) with slight modification. Briefly, rice malt wort was boiled together with hop extracts for 30 min and thereafter, allowed to cool. Undissolved particles were removed and the filtered wort was transferred into fermenters. Already activated yeast (3g) culture (*Saccharomyces pastorianus*) was pitched into the fermenting vessel at 20 °C and fermentation was carried out at 10 – 20 °C for 8 days. Green beer was filtered and allowed to age for 21 days. Matured/draft beer was siphoned into sterile bottles, pasteurized at 60 °C for 15 min, and subsequently, analysed.

### 2.4. Evaluation of rice (grain) samples

Grain quality analyses (such as thousand corn weight, germinative energy, germinative capacity, degree of steeping, etc.) are important for the evaluation of suitability of rice variety for malting and brewing (Marconi, Sileoni, Ceccaroni & Perretti, 2017). In this current work,



thousand corn weight, germinative energy, germinative capacity, and degree of steeping were determined.

#### 2.4.1. Determination of thousand corn weight (TCW)

This was determined according to the method described by Esiapa (1994). Hundred (100) grains of paddy rice randomly selected from the bulk were weighed using a weighing balance. Each weight was multiplied by 10 to obtain the 1000 kernel weight. Determinations were done in triplicate.

#### 2.4.2. Determination of germinative capacity (GC) and germinative energy (GE)

GC measures grain viability, whereas GE measures the extent to which grain will germinate in a standardized test. Both rapid and complete germination are well-known essential features of good malt. For this current work, the GE and GC (presented in percent [%]) of rice samples was determined using the recommended method of analysis of the Institute of Brewing (IoB) (2007).

$$\text{Germinative energy (\%)} = \frac{\text{Number of viable grains}}{\text{Total number of grains}} \times 100 \quad \text{Eq. 1}$$

$$\text{Germinative capacity (\%)} = \% \text{ Germinative energy} - \% \text{ Dormancy} \quad \text{Eq. 2}$$

#### 2.4.3. Degree of steeping (DoS)

DoS measures the amount of water readily absorbed by the grains. DoS expressed as percentage (%) was determined by the method described by Kunze (2005) with slight modification. One hundred grams rice kernels of each variety, the moisture content of which has been previously determined were soaked in a 100 ml beaker containing 50 ml of distilled water at ambient temperature ( $28^{\circ}\text{C} \pm 2$ ). Steeping was done continuously until constant weights were attained and recorded. Soak waters were drained off the grains by the use of sieves. From the increase in mass, the degree of steeping was calculated as;

$$\text{Degree of steeping (\%)} = \frac{X}{W_i} \times 100 \quad \text{Eq. 3}$$

191 Where  $X = \frac{W_i \times (D + Mc)}{W_f}$

192  $W_i$  = Mass of rice grain before steeping

193  $W_f$  = Mass of rice grain after steeping

194  $MC$  = Moisture content of rice grain

195  $D = W_f - W_i$

## 196 2.5. Characteristic analyses of rice malt, wort and beer samples

### 197 2.5.1. Rice malt analyses

198 Malt analyses are carried out in accordance with standard methods of the Institute of  
199 Brewing (IoB), European Brewing Convention (EBC) and American Society of Brewing  
200 Chemists (ASBC) for several purposes such as to provide data for the maltster to use for quality  
201 control and to guide process adjustments, to provide a basis for product valuation, for prediction  
202 of extract recovery, to indicate the potential value of the malt and whether or not a particular  
203 malt is likely to give production difficulties (Briggs, 1998).

#### 204 2.5.1.1: Determination of cold water extract (CWE)

205 CWE measures the pre-formed water-soluble substances present in malt (Briggs, 1998).  
206 CWE (presented in g/100g) was determined using method recommended by Institute of Brewing  
207 (IoB) (2007) and was calculated using equation below:

$$\text{Cold Water Extract (\%)} = \frac{(G - 100)}{3.86} \times 20 \quad \text{Eq. 4}$$

208 where,

209  $G$  = the excess degrees of gravity of the filtrate at 15.5 °C as 1000

210 i.e.  $G = 1000 (S.G - 1)$

#### 211 2.4.1.2. Determination of hot water extract (HWE)

HWE measures the extractable materials derived from malt after a small scale mashing process (Briggs, 1998). HWE expressed as liters degrees/kg (°L/kg) was determined using method recommended by Institute of Brewing (IoB) (2007) and was calculated using the equation below;

$$\text{Hot Water Extract (°L/kg)} = \frac{G \times V}{M} \quad \text{Eq. 5}$$

where,

G = the excess degrees of gravity of the filtrate at 15.5 °C as 1000

i.e.  $G = 1000 (S.G - 1)$

V = Volume of wort in Litres (L)

M = Mass of malt in Kilogram (kg)

#### 2.5.1.3. Determination of diastatic power (DP)

DP measures the amount of enzyme in malt available to convert complex carbohydrates/starches into fermentable sugars (Ackley, 2018). DP expressed in lintner degree (°L) was determined using method recommended by Institute of Brewing (IoB) (2007) and was calculated using the equation below;

$$DP = \frac{(2000 - 200)}{(xy - xs)} \quad \text{Eq. 6}$$

where,

x = mL of malt extract

y = mL of converted starch to 5 mL of the Fehling's solution

s = Titre for starch blank

#### 2.5.1.4. Determination of moisture content (MC) and total nitrogen (TN)

Malt with higher diastatic power (DP), cold water extract (CWE) and hot water extract (HWE) were selected for wort production/brewing trial. Only these were subject to determinations of moisture content (MC) presented in g/100g (wet basis) via the method

described in AOAC (2006), and total nitrogen (TN) presented in g/L via the Kjeldahl method (European Brewery Convention, 2006).

#### 2.5.1.5. Malting loss (ML)

Malting loss (ML) after germination was determined according to the method described by Adebawale *et al.*, (2010) by weighing the rice grains before and after malting. The weight of 100 grains of rice was recorded before malting and the weight of the malted grains after the rootlets were removed by hand was also recorded. Malting loss was expressed as percentage (%) on dry matter basis.

$$\text{Malting loss (\%)} = \frac{\text{Weight of unmalted grain} - \text{Weight of malted grain}}{\text{Weight of unmalted grain}} \times 100 \quad \text{Eq. 7}$$

#### 2.5.1.6. Malt yield (MY)

Malt yield (MY) after germination was determined according to the method described by Adebawale *et al.*, (2010) by weighing the rice grains before and after malting. The weight of 100 grains of rice was recorded before malting and the weight of the malted grains after the rootlets were removed by hand was also recorded. Malt yields were expressed as percentage (%) on dry matter basis.

$$\text{Malt yield (\%)} = \frac{\text{Weight of malted grain}}{\text{Weight of unmalted grain}} \times 100 \quad \text{Eq. 8}$$

### 2.5.2. Rice wort analyses

#### 2.5.2.1. Determination of pH

pH of rice malt wort was determined using the method described by AOAC (2004). Digital pH meter calibration used buffer 4, 7 and 9 solutions at 25 °C. pH conducted measurement required electrode (probe) dipping into each 25 mL pipetted wort sample, allowed to stabilize before reading off.

#### 2.5.2.2. Determination of total soluble nitrogen (TSN)

TSN measures the nitrogen materials (amino acids, peptides and polypeptides) solubilized by proteolysis during malting and extracted during mashing (Agu & Palmer, 1998;

258 Noonan, 2003). TSN of rice malt wort, expressed in g/L was determined using Kjeldhal method  
259 (Institute of Brewing (IoB), 2007).

#### 260 2.5.2.3. Determination of apparent brix ( $^{\circ}\text{Bx}$ )

261 Brix of rice malt wort was determined using a Milwaukee Digital brix Refractometer  
262 Model MA871 (Milwaukee Instruments, NC - USA) (Montañez-Soto *et al.*, 2013), which  
263 involved refractometer standardized with distilled water at 20 °C until brix value read zero,  
264 followed by two drops of wort sample on the lens (sensitive surface), and measurement  
265 conducted subsequently.

#### 266 2.5.2.4. Determination of kolbach index (KI)

267 KI measures the degree/extent of protein modification/degradation, as a ratio of TSN in  
268 wort to TN in the malt (Bamforth, 2003; Olivier & Colicchio, 2012). KI expressed in %, was  
269 calculated consistent with Analytical - EBC (1998) method, using the equation below:

$$\text{KI} = \left( \frac{\text{TSN}}{\text{TN}} \right) \times 100 \quad \text{Eq. 9}$$

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#### 272 2.5.2.5. Determination of free amino nitrogen (FAN)

273 FAN of rice malt wort was determined by Ninhydrin method (European Brewery  
274 Convention, 1998) with slight modifications. The sample (1mL) diluted with deionised water to  
275 100 mL, then 2 mL of diluted sample mixed with 1 mL of colour reagent, placed in boiled water  
276 for 16 min, allowed to cool to 20 °C. Diluted solution (5 mL) was added, followed by  
277 measurement of optical density at 570 nm. Blank was determined with 2 mL of deionized water.  
278 Glycine standard solution was checked using 2 mL of glycine solution. The FAN content was  
279 calculated and expressed in mg/L.

#### 280 2.5.2.6. Determination of dextrose equivalence (DE)

281 DE measures the amount of reducing sugars present in a sugar product, relative to  
282 glucose (Dziedzic & Kearsley, 1995) determined on rice malt wort, using the Lane and Eynon  
283 Fehling's solution method as previously described (International Starch Institute, 1999).

#### 284 2.5.2.7. Determination of original extract (OE)

OE measures wort density compared to that of water at equal volume and temperature (ASBC, 2009). OE of rice malt wort presented in g/100g was calculated from an approximate Plato value as previously described (Kunze, 2004), calculated using equation below:

$$\text{Specific Gravity (SG)} = (\text{Mass percent} \times 0.004) + 1 \quad \text{Eq. 10}$$

where Mass percent  $\equiv$  Apparent brix value

$$\text{Original Extract (g/100g)} = 259 - \left( \frac{259}{\text{SG}} \right) \quad \text{Eq. 11}$$

#### 2.5.2.8 Determination of wort sugar profile

The sugar profile of rice malt wort was determined using HPLC according to the method described in AOAC Official Method 982.14 (2006).

#### 2.5.3. Rice malt beer analyses

Rice malt beer was characterized using the following Analytical-EBC methods (European Brewery Convention, 2007).

##### 2.5.3.1. Determination of pH, colour, and apparent extract

pH was determined using the EBC method 9.35, similar to AOAC (2004). Colour presented in °EBC was determined using the Spectrophotometric Method (EBC method 9.6). Apparent extract (AE) presented in g/100g was determined using the EBC method 9.43.1.

##### 2.5.3.2. Determination of alcohol and turbidity

Alcohol by volume (%ABV) was determined by distillation (EBC method 9.2.1). Turbidity presented in NTU (Nephelometric Turbidity Unit) was determined by EBC method 9.10.

##### 2.5.3.3. Determination of sensory attributes

A hedonic scale test was used to evaluate the sensory attributes of beer samples according to the method reported by Iwe (2002). This specifically involved comparing the rice malt beer samples with the commercial lager beer. The sensory evaluation was carried out by 20 ordinary frequent beer drinkers (semi-trained panellists) of different age groups (20–36 years old). The prerequisites for participating in the study were that the individual consumed beer and showed interest in participating in all test sessions. Importantly, the participation in this sensory evaluation was voluntary, and oral consent was obtained prior to participation. The coded rice malt beer samples were randomly served at temperatures of about 10 °C. Participants were

served with 4 series of beer samples in transparent glass cups and the degree of liking was rated using a nine-point hedonic scale with the ratings of 9 as liked extremely and 1 as disliked extremely for five main attributes i.e., colour, aroma, taste, mouthfeel and appearance; while overall acceptance of the samples was evaluated by taking the average of other attributes. The panellists drank potable water to rinse/clean their mouth between tastings to avoid cross-contamination between samples. After tasting, score sheets were filled by the tasters.

## 2.6. Statistical analysis

One way analysis of variance (ANOVA) was carried out using IBM SPSS version 20 Software (IBM, New York, USA). Results, of duplicate measurements, were considered statistically significant at  $p < 0.05$ , and expressed as mean  $\pm$  standard deviation (SD). Mean differences were resolved using least significant differences (LSD) at post-hoc conditions. Where required, simple correlation was performed and R-square values reported.

## 3. RESULTS AND DISCUSSION

### 3.1 Changes in grain quality of rice grain

#### 3.1.1. TCW

Rice grain varied significantly ( $p < 0.05$ ) in TCW (25.81 – 27.01 g) across rice varieties (Table 1). Specifically, TWC, GE, and GC peaked at NERICA 7 with 27.01 g, 95.00 %, and 95.50 %, respectively. The range/variations of TCW, GE, and GC in this current study competes well with those reported by Osuji et al., (2019), and could have arisen due to differences in soil composition, weather condition, moisture content or grain production/harvest period. Essentially, the TCW has been understood to help in identifying grain/seed density, size, and variety (Tokpah, 2010; Osuji et al., 2019). Higher TCW or large grain size could also serve as an indicator of high starch content (Ayernor and Ocloo, 2007). On this premise, therefore, the NERICA 7 might have a higher starch content compared to other rice varieties in this current study.

#### 3.1.2. GE and GC

The rice grain's GE (86.50 – 95.00 %) and GC (92.50 – 95.50 %) differed significantly ( $p < 0.05$ ) across rice varieties (Table 1). The germinative (GE and GC) outcomes of the rice grains of this current study seems favourable, and promises a good viability during malting

(Adebawale et al., 2010; Osuji et al., 2019). Changes in GE and GC across the studied rice varieties might have occurred with water absorption rates, TCW (kernel size), rice harvest period as well as starch content. Besides, the prompt grain germination of above 90 % of the grain would be considered a good quality malt attribute (Agbale et al., 2007). In the current work, the rice varieties obtained acceptable grain germination of above 85 %, which makes it acceptable for malting purposes. Similar trends of over 85 % germinative properties were reported (Bam et al., 2006; Hammond & Ayernor, 2001; Ameko et al., 2013). Moreover, higher GE enhances the enzyme activities as well as seed vigour (Agbale, 2007). Additionally, both grain and malting qualities/characteristics are well-known to ascertain a cereal to become an acceptable substitute for barley. Therefore, the rice grain's GE (86.50 – 95.00 %) and GC (92.50 – 95.50 %) of current study shows a high promise as barley substitute in brewing.

### 3.1.3. DoS

The DoS (49.96 – 55.00 %) obtained significant differences ( $p < 0.05$ ) across rice varieties (Table 1). DoS is the amount of water absorbed by the grain during steeping and it is an integral step in malting process because development of enzyme and formation, as well as metabolic transformation is influenced by it. In the current work, the DoS was highest (55.00 %) at FARO 44, and least at NERICA 7 (49.96 %). Results showed that rice varieties with higher DoS obtained higher MY and lower ML, probably due to decreased metabolic processes in the rice varieties of the current study. Besides small kernels taking up more water compared to larger kernels, it is also believed that the grains from inland regions would swell and germinate faster compared to grains from maritime regions (Kunze, 2005).

## 3.2. Changes in CWE, HWE, DP, MY, ML, MC and TN of rice malt

### 3.2.1. CWE, HWE and DP

Malt varied significantly ( $p < 0.05$ ) in CWE (10.95 – 23.16 g/100g), HWE (51.06 – 206.48 °L/kg), and DP (22 – 150 °L) across rice varieties (Tables 2, 3 and 4). Specifically, CWE/HWE/DP peaked at FARO 44 (22.88 g/100g; 136.56 °L/kg; 150 °L), FARO 57 (22.13 g/100g; 170.18 °L/kg; 148 °L), and NERICA 7 (23.16g/100g; 206.48 °L/kg; 143 °L), respective to  $S_{18}G_3K_{55}^0$  (18 h steeping, 3 days germination, 55°C kilning),  $S_{30}G_2K_{50}^0$  (30 h steeping, 2 days germination, 50°C kilning) and  $S_{24}G_3K_{55}^0$  (24 h steeping, 3 days germination, 55°C kilning) combinations, and trended: FARO 44 ( $S_{18}G_3K_{55}^0$ ) > FARO 57 ( $S_{30}G_2K_{50}^0$ ) > NERICA



7(S<sub>24</sub>G<sub>3</sub>K<sub>55</sub><sup>o</sup>). Outside this (specific steeping duration, germination periods and kilning temperatures), CWE/HWE/DP produced no peaks (Tables 1, 2 and 3). Rice malt CWE (10.95 – 23.16g/100g) range herein agrees with those reported by Kasetsart (2007). Based on CWE (15 – 22g/100g) range data (Briggs 1998; Briggs *et al.*, 2004), rice malt herein represented a ‘good modification’. By hydrating the grist during grain modification, cold mashing (20 °C) solubilises enzymatically-degraded compounds (Dahiya *et al.*, 2017). According to European Brewing Convention (EBC) and American Society of Brewing Chemists (ASBC), HWE range of 51.06 – 206.48 °L/kg parallel to ~13 – 54 g/100g soluble extract (SE) suggested HWE herein to be greater than two fold of CWE. Moreover, DP of rice malts (23 – 150 °L) corroborate with barley (50 – 150 °L) (BYO (2019a), (35 – 40 °L) (O’Rourke, 2002a) and sorghum (20 - 23°L) malts (Byrne, Donnelly & Carrol, 1993). Malt DP range 35 – 40 °L can convert its own starches (BYO, 2019b) probably with a longer conversion time. Malt enzymes that degrade starch and obtain high extract yield depict good malt characteristics (Sabramanian *et al.*, 1995; Muoria & Bechtel, 1998).

CWE, HWE and DP of rice malt increased with steeping duration at FARO 44 (S<sub>18</sub>G<sub>3</sub>K<sub>55</sub><sup>o</sup>), FARO 57 (S<sub>30</sub>G<sub>2</sub>K<sub>50</sub><sup>o</sup>) and NERICA 7 (S<sub>24</sub>G<sub>3</sub>K<sub>55</sub><sup>o</sup>) (Tables 1, 2 and 3). The positive correlation results [FARO 44 (R<sup>2</sup> = 0.769), FARO 57 (R<sup>2</sup> = 0.700) and NERICA 7 (R<sup>2</sup> = 0.588)] show DP’s significant role in HWE of rice malt, corroborating with (correlation) data of millet malt (Eneje, Odibo & Nwani, 2012). Besides small-sized kernel of cereals modifying at a faster rate over large ones (Agu, 2009), the grain physiological activities progressing during malting (Kunze, 2004; Ogbonna, 2002; Osuji, Ofoedu & Ojukwu, 2019) can influence CWE, HWE and DP of malt. Starch-degrading enzymes like alpha-amylase, beta-amylase, limit dextrinase and alpha-glucosidase (Buchholz, Volker & Uwe, 2005; Evans, Li & Eglinton, 2010), lipases, proteases and other enzymes could also influence DP of malt (Briggs, 1998). Low DP of rice malts corroborate with lower protein content of grain (Agu & Palmer, 1998). Mashing schedule, high gelatinization temperature, and kilning/malting conditions might be contributing to differences in CWE, HWE and DP of rice malt in this study.

### 3.2.2. MY, ML, MC and TN

To a maltster, MY is an important attribute because it gives an indication of the amount of recoverable soluble extracts from the malted grain (Osuji *et al.*, 2019). Additionally, the malt quality analyses guides the maltster/brewer on both variety selection and effectiveness of malting

process for optimised output, to achieve sustainable malt brewing process (Briggs, 1998). On the other hand, ML is the measure of metabolic activity associated with grain germination, which increases with germination period. In the current work, the MY (87.11 – 92.65 %) and ML (6.03 – 10.80 %) of rice malt changed significantly ( $p < 0.05$ ) across varieties (Table 5). Peak (10.80 %) ML and least (87.11 %) MY can be seen at NERICA 7 while Peak MY (92.65 %) and least (6.03 %) ML can be seen at FARO 44. Probably, these variations in ML and MY might have been influenced by the malting process (Ofoedu, 2018; Osuji et al., 2019). Besides moisture loss during kilning as well as physiological activities associated with germination, the changes in TCW, GE and GC, would perhaps influenced both MY and ML. We opine that this might be so, considering the peak TCW, GE, and GC values obtained at NERICA 7, as well as the least MY obtained at FARO 44.

MC and TN of rice malts specific to FARO 44 ( $S_{18}G_3K_{55}^0$ ), FARO 57 ( $S_{30}G_2K_{50}^0$ ) and NERICA 7 ( $S_{24}G_3K_{55}^0$ ) were determined. MC (5.19 – 6.43g/100g) and TN (13.10 – 15.70g/L) varied significantly ( $p < 0.05$ ), with the following trends for MC (NERICA 7 = 6.43g/100g > FARO 44 = 5.52g/100g > FARO 57 = 5.19g/100g) and TN (FARO 44 = 15.70g/L > FARO 57 = 14.30g/L > NERICA 7 = 13.10g/L) (Table 5). MC of rice malt (5.19 – 6.43g/100g) was above those of Munich (3.0 – 4.8g/100g) as well as two-row (2.0 – 4.3g/100g) barleys (Noonan, 2003). Increase in MC of malts can decrease the extract potential, which might lower original gravity of wort (BYO, 2019a). Malt closer to 1.5g/100g MC is of less risk to the mould growth (Noonan, 2003). Moisture level of grain is reduced with high drying temperature(s) or prolonged drying time(s) (Osuji et al., 2019). Whereas low MC can prolong food shelf life (Alozie *et al.*, 2009), high MC can enhance its microbial spoilage (Ijarotimi, 2012). TN of rice malt (13.10 – 15.70g/L) fell within those of ale/lager (14.00 – 18.00g/L) (O'Rourke, 2002a), and sorghum (14.70 – 17.40g/L) types (Agu & Palmer, 1998). Rice variety as well as malting conditions may contribute to the MC and TN differences in rice malt of this study. As nitrogen via amino acids is required for yeast growth, hydrophobic nitrogen (from malt) provides foam and head retention in beer (O'Rourke, 2002a).

### 3.3. Changes in sugar profile of rice malt wort

To the brewer, the importance of sugar wort parameter/composition underpins the influential success of fermentation. Additionally, the sugar profile of rice malt wort is the

outcome of the enzymatic activities during mashing. In the current work, the rice malt wort yielded a combination of sugars, such as maltose (14.63 – 15.34 %), maltotriose (12.26 – 16.40 %), glucose (10.84 – 11.63 %), sucrose (2.32 – 2.83 %), raffinose (0.05 – 0.07 %) and maltotetraose (0.44 – 0.63 %), all of which varied significantly ( $p < 0.05$ ) across varieties (Table 6). Clearly, it was not difficult to differentiate the sugars herein based on amounts obtained across the studied rice varieties. Specifically, whereas the maltose, glucose and maltotriose clearly obtained higher amounts, the sucrose, maltotetraose and raffinose obtained lower amounts. Both maltose and maltotriose, well-known as predominant sugars found in wort are, seemed to be noticeably lower than the values obtained by Ofoedu et al., (2019).

Malting conditions, mashing program as well as the nature/type of (exogenous) enzymes used could have some impact on the variations in the rice malt wort sugar profile. Additionally, the lower sugar concentrations in the rice malt wort might be attributable to limit dextrins produced in higher amounts, and maybe, tannins binding with malt's amylase enzyme (Okolo et al., 2010). Sucrose, among the major soluble sugars and natural component of matured kernel, is neither produced during malting nor hydrolysis/mashing, but however, could be depleted naturally during germination in sustaining (rice) malt metabolism. This might explain the significantly low sucrose concentration in the rice malt wort. The presence of maltotetraose and raffinose in the wort could be an indication of oligosaccharides resulting from limit dextrins formation due to the different amylolytic enzymes working in the rice malts (Marconi et al., 2017).

### 3.4. Changes in pH, TSN, Brix, KI, FAN, DE and OE of rice malt wort

#### *3.4.1. pH and TSN*

Resembling ( $p > 0.05$ ) across rice varieties (FARO 44 = 5.40 > FARO57/NERICA 7 = 5.30), pH of wort (Table 5) compares well with another previously published (rice wort) data (4.98 – 6.08) (Kasetsart, 2007) but slightly below those of barley ale/lager (5.6 - 5.9) (Palmer, 2006). During mashing and wort boiling, heat treatment can dissociate the calcium ion ( $\text{Ca}^{2+}$ ) bound with both phosphates ( $\text{K}_2\text{PO}_4$ ) and polypeptides, forming insoluble compounds, releasing hydrogen ion ( $\text{H}^+$ ), and decreasing wort pH (Palmer, 2006). Increased wort acidity enhances both protein coagulation and yeast growth, and inhibits microbial contamination (O'Rourke, 2002b).

TSN of rice malt wort resembled ( $p > 0.05$ ) across rice varieties (NERICA 7 = 5.80g/L > FARO 57 = 5.60g/L > FARO 44 = 5.40g/L (Table 7), with the range (5.40 – 5.80g/L) corroborating

favourably with those of sorghum (5.00 – 7.00g/L) (Agu & Plamer, 1998) and typical lager barleys (5.70 – 6.60g/L) (O'Rourke, 2002a). Aided by denaturation and precipitation of solubilized proteins, high gelatinization temperature of rice starch reduces TSN level in wort. Steeping could enhance the loss of some soluble nitrogenous compounds, like amino acids (Briggs, 1998). Amino acid dissolution could increase in TSN (during germination) (Banusha & Vasantharuba, 2013), which would cease if acrospires reach from 3/4 to 7/8 of grain length (Briggs et al., 2004). As the need of wort TSN increases, it becomes undesirable if protein degradation raises the TSN levels higher than required, to reduce foam formation, abnormal fermentation (Sadosky, 2007), and haze formation (Briggs et al., 2004).

### 3.4.2. Brix and KI

Brix of rice malt wort differed significantly ( $p < 0.05$ ) across rice varieties (FARO 57 = 16.36g/100g > FARO 44 = 14.65g/100g > NERICA 7 = 13.88g/100g) (Table 7). Peak brix at FARO 57 suggested increased malting accessibility to substrate (starch) with enhanced enzymatic hydrolysis. Grain kernel size differences in rice varieties might affect the endosperm starch composition when malted/mashed, which may well vary the brix values. Varying malting conditions influencing how the grain responds to its modification, could actually differ during germination. Brix value could, therefore, be affected by amount/type of sugars in wort, which serves as a nutrient for yeast (Pedley, 1996).

KI of rice malt wort differed significantly ( $p < 0.05$ ) across rice varieties (NERICA 7 = 44.27% > FARO 57 = 39.16% > FARO 44 = 34.39%) (Table 7) with (34.39 – 44.27%) resembling those of typical lager malt (34 - 44%) (O'Rourke, 2002a). Malts can be classified, based on degree of modification (BYO, 2019b), namely: a) under modified (KI values between 30 – 35%), b) well modified (KI values above 35%), c) over modified (KI values above 45%) malts. Specifically, wort KI of FARO 44 (34.39%) falls within 'under modified', whereas FARO 57 (39.16%) and NERICA 7 (44.27%) falls within 'well modified' malts. Further, Bamforth (2003) reported 'well modified' malt with KI range of 38 – 42%. Besides malting enabling KI to increase with germination, the small-size of FARO 44 kernel may corroborate with lower (KI) value. Thinner kernel/grain size taking up water faster (Kunze, 2004; Osuji et al., 2019) might sustain a higher TN relative to the larger ones (Briggs, 1998). The reduced HWE, CWE and KI values might help in defining those of FARO 44 as 'under modified malt'. However, the higher

TSN (NERICA 7 = 5.80g/L) and KI values (NERICA 7 = 44.27%) would suggest a positive association of grain size with HWE, CWE and TSN of the current study.

### 3.4.3. FAN, DE and OE

FAN of rice malt wort differed significantly ( $p < 0.05$ ) across rice varieties (NERICA 7 = 117.34mg/L > FARO 57 = 112.23mg/L > FARO 44 = 108.56mg/L) (Table 7), and compared well with those of sorghum (94 – 216 mg/L) (Agu & Palmer, 1998), maize (100 – 169mg/L) and rice (95 – 138mg/L) (Taylor, Dlamini & Kruger, 2013) malts. Increased amino acids/protein modification might favour the peak FAN in NERICA 7 with proteolytic enzyme activity. As principal nitrogen source in wort, FAN depicted hydrolysed (soluble) proteins during mashing (Agu & Palmer, 1998; Russell, 2006), summed up by amino acids, ammonium ions and small peptides (dipeptides and tripeptides) (Stewart, Hill & Lekkas, 2013; Lekkas et al., 2005; Pugh, Maurer & Pringle, 1997). Typical lager malt with FAN between 100 and 140mg/L can enhance efficient yeast cell growth and fermentation performance (Lekkas et al., 2005) to achieve a trouble-free fermentation (Briggs et al., 2004). Besides, FAN can also help to predict yeast's healthy growth, viability/vitality, and fermentation efficiency (Hill & Stewart, 2019). Though FAN strongly depends on malting conditions (Briggs, 1998), some FAN components (alongside reducing sugars) during mashing might provide minor flavour precursors that undergo maillard reaction (Hill & Stewart, 2019; Hughes, 2009). Despite FAN influencing other fermentation factors (like cell biomass, growth, pH, viability and attenuation rate) (Shimizu et al., 2002), too high FAN is undesirable given the resultant excessive yeast growth, which could affect beer stability (BYO, 2019b). Malts with higher FAN levels require adjuncts, which can act as nitrogen diluent, but would contribute little-to-no TSN to the wort (Briggs et al., 2004).

Resembling ( $p > 0.05$ ) across rice varieties (FARO 57 = 40g/100g > FARO 44 = 39g/100g > NERICA 7 = 37g/100g), the peak DE of rice wort (Table 7) suggested increased hydrolysis. The slight DE variations in wort might reflect the differences in amylose-amylopectin ratio of rice starch. This is because the amylose can be more completely hydrolyzed than amylopectin, the latter limited by beta-limit dextrin due to branched chains (Osuji & Anih, 2011). Varietal differences, varying malting conditions as well as amount/type of enzymes developed in the rice grain particularly during malting might also govern both degree of hydrolysis and hydrolysates types obtained. The maltose and maltotriose remain the most abundant sugars present in

malt/wort (Goldhammer, 2008; Palmer, 2009), which could also influence the DE of wort (Ofoedu et al., 2020).

Resembling ( $p>0.05$ ) across rice varieties (FARO 57= 12.66g/100g > FARO 44= 11.15 g/100g > NERICA 7 = 9.68g/100g), OE of rice malt wort (Table 7), neared those of millet (~10 g/100g), sorghum (10.42g/100g) and barley (11.0 g/100g) malts (Reginald, 1995), and compared well with other reported ranges (7.5 - 9, 8 – 9.5, 11-14, and 12.5 – 16 g/100g) of different barleys used for ale beers (Papazian, 2006). Principally, original gravity (density) of wort is four times the original extract by Plato scale. Well-known, water density is 1.0000 at standard temperature and pressure (STP); if respective wort density of FARO 44, FARO 57 and NERICA 7 were 1.04448 (11.15 g/100g), 1.05064 (12.66 g/100g) and 1.03872 (9.68 g/100g), the corresponding wort will be 44.48°, 50.64° and 38.72° of excess gravity. Thus, wort densities consider the solution factors/mixtures of dissolved carbohydrate materials, soluble proteins and minerals typically emerging from malted cereal materials. Besides grain mashing to considerably influence OE of wort, most grain modified products (that is, cell wall degradation and enzymatic breakdown) in endosperm's protein-starch matrix (Agu & Palmer, 2001) would be released (into the wort) as soluble extracts.

### 3.5. Changes in pH, colour, AE, ABV, turbidity, and sensory attributes of rice malt beer

#### *3.5.1. pH, colour and AE*

Resembling ( $p>0.05$ ) across rice varieties (FARO 57= 3.90 > FARO 44 & NERICA 7= 3.80), pH of beer (Table 8) appeared lower than those of barley (4.1 – 4.5) (Bamforth, 2001) as well as sorghum (3.90 – 4.10) beers (Iwouno, Ofoedu & Ofoedum, 2019). Low pH in rice malt beer might be due to organic (weak) acids excreted by yeast with excess CO<sub>2</sub> (which provides relative amounts of carbonic acid) during fermentation. Low beer pH also depicts its sharpness of taste. When pH is below 4, taste further sharpens with increased foam stability and head retention (Bamforth, 2009). By decreasing buffering capacity, lower pH increases yeast growth, removes colloidal particles of proteins-polyphenol complexes (and other insoluble materials) and inhibits microbial growth (in beer/wort) (Leiper & Miedl, 2006). In addition, pH in beer, determined by organic acids, e.g., acetic, lactic, pyruvic and citric acid, can influence its flavour.

Beer colour depicts its appearance and its critical to (product) acceptance, being the first quality attribute consumers perceive (Leon, Mery, Pedreschi, & Leon, 2006; Osuji, Ofoedu, Omeire & Ojukwu, 2020). Beer colour resembled ( $p>0.05$ ) across rice varieties (FARO 57= 3.73

°EBC > FARO 44 = 3.70 °EBC > NERICA 7 = 3.20 °EBC) (Table 8). Although fairly above those of another rice malt (1.70 – 2.60 °EBC) (Mayer et al., 2017), rice malt beer herein compared well with those of typical barley (2.00 – 4.00 °EBC) (O'Rourke, 2002a), but not so for sorghum (6.0 – 6.6 °EBC), barley double crown (~7.5 °EBC) and barley rex (~14.0 °EBC) malt lager beers (Olatunji et al., 1993). As °EBC increases, beer colour darkens. When assessed by Saveur Bierre colour chart (Anon., 2020), rice malt beer colour range herein depicted type pale yellow lager. Beer colour variations could be as a result of either decolourization of the (beer colour) substance as pH dropped (Kunze, 2004), changes/differences in malt colour, or inconsistencies in the colour formation of wort during boiling process (Briggs et al., 2004). Phenols (tannins) are natural organic compounds in malts/hops, which change beer colour from pale yellow to dark brown via Maillard reaction/caramelization (Whistler & Bemiller, 2008; Panthare, Opara & Al-Said, 2013). In addition, maillard reaction and caramelization occurring independently/simultaneously would influence colour formation/intensity (Kunze, 2004). Other factors like pH level, yeast strain, hop usage, maturation duration and specialty ingredients can influence beer colour.

AE resembled across rice varieties ( $p > 0.05$ ) (NERICA 7 = 4.93 g/100g > FARO 44 = 4.59 g/100g > FARO 57 = 4.57 g/100g) (Table 8). Noticeably, there appears some reduction in gravity of wort from 9.68 – 12.66 g/100g (Table 4) to 4.57 – 4.93 g/100g (Table 5) in the final rice malt beer. Dissolved solids (sugars, amino acids, minerals, among others) in wort utilized by yeast during fermentation might reduce the final beer gravity. As yeast utilizes sugars (and other compounds) to produce alcohol, the gravity of wort may well decrease (Boulton, 1991; Briggs et al., 2004). Moreover, fermentability of wort depicts the proportion of dissolved solids (extract) that can be fermented. In other words, 59 % (FARO 44), 64 % (FARO 57) and 49 % (NERICA 7) of fermentable materials in these worts utilized by yeast produced AE of 4.59 g/100g, 4.57 g/100g and 4.93 g/100g, respectively.

### 3.5.2. Alcohol content and turbidity

Alcohol content of beer, although differing significantly ( $p < 0.05$ ) across rice varieties (FARO 57 = 4.13%ABV > FARO 44 = 3.54 %ABV > NERICA 7 = 2.82 %ABV) (Table 8), fell within a generally anticipated range (4 – 6 %ABV) (Polan, Eisner & Vytras, 2015), somewhat above 2.55, 3.09 and 3.65 %ABV of millet, sorghum and barley beers, respectively (Reginald, 1995). FARO 57 with peak fermentability of 64% corresponded to 4.13 %ABV, and NERICA 7

with least fermentability of 49% corresponded to 2.82 %ABV. This suggested alcohol concentration in beer not solely dependent on the original extract/gravity of wort, but more likely on the availability of fermentable extracts, readily utilized by the yeast. Whilst the fermentable extracts especially sugars in wort remain the beer quality index (Jordao, Vilela & Cosme, 2015), its concentration (and subsequent utilisation) in the wort can help to determine the improved fermentation efficiencies (Zhao et al., 2008).

Resembling ( $p>0.05$ ) across rice varieties (FARO 44 = 5.30NTU > FARO 57 = 4.80NTU > NERICA 7 = 4.30NTU), beer turbidity (Table 8) were above those of sorghum (1.6 – 2.0NTU) and barley malt (3.2NTU) lager beer (Olatunji et al., 1993), but below those of sorghum (red) (South Africa) (~12.8 NTU), sorghum (white) (Australia) (~28 NTU), sorghum (white) (Nigeria) (~33.2 NTU) malt beers (Aisen & Muts, 1987), and sorghum beer clarified with different filter aids (8.28 – 26.56 NTU) (Iwouno et al., 2019). Considering 1.00 EBC equals 4.00 NTU, the beer turbidity can be graded based on degree of haziness, which includes; brilliant: 0 – 0.50 EBC (0 – 2.00 NTU); almost brilliant: 0.50 – 1.00 EBC (2.00 – 4.00 NTU); very slightly hazy: 1.00 – 2.00 EBC (4.00 – 8.00 NTU); slightly hazy: 2.00 – 4.00 EBC (8.00 – 16.00 NTU); hazy: 4.00 – 8.00 EBC (16.00 – 32.00 NTU) and very hazy: > 8.00 EBC (> 32.00 NTU) (Callemien & Collin, 2009). Herein, the rice malt beer (4.30 – 5.30 NTU) would be considered as ‘very slightly hazy’. Some proteins not removed during wort boiling, surviving fermentation, and finding its way into the beer might equally cause the haze (Briggs et al., 2004). Besides the origin of haze formation as either biological (e.g., bacteria, cell debris, yeast) or non-biological (inorganic, carbohydrate-based and protein-polyphenol complexes) (Siebert, Carrasco & Lynn, 1996; Stewart, 2004; Briggs et al., 2004), beer haziness might be due to ineffective filtration, non-flocculant yeast, and or poorly modified malt/filter aids (Steiner, Becker & Gastl, 2010). Coloured compounds such as melanoidins (Iwouno et al., 2019), cereal/malt-type, and differences in chemical composition/processing methods can influence beer turbidity. In addition, centrifugation and microfiltration used during commercial production can also increase beer clarity (Kuiper et al., 2002; Shotripuk et al., 2005).

### 3.5.3. Sensory attributes

The sensory attributes (colour, aroma, taste, mouthfeel, appearance, and overall acceptability) of rice malt beers compared with commercial lager beer is shown in Table 9. The



colour (6.66 – 8.71), mouthfeel (6.57 – 8.51), appearance (6.24 – 8.61) and overall acceptability (6.94 – 8.40) of beer samples differed significantly ( $p < 0.05$ ), but not for taste (7.69 – 8.19) and aroma (7.54 – 7.99) ( $p > 0.05$ ). Based on the hedonic scale, the panellists viewed the colour of the rice malt beers (6.66 – 6.91) as pale yellow colour and compared to the commercial lager beer (8.71). The panellists considered the rice malt beers as slightly liked compared to the commercial lager beer that was liked very much. The colour variations in the beer samples may be due to differences in kilning temperatures and chemical compositions (sugars and amino acids) that facilitates formation of melanoidin in beer (Osuji et al., 2020; Iwouno et al., 2019). The panellists obtained mouthfeel of rice malt beers (6.57 – 6.96) as slightly liked/relatively flat compared to the commercial lager beer (8.51) which was liked very much. The variations in mouthfeel of beer samples may be due to varying concentrations of residual sugars, higher alcohols as well as organic acids in the beer (He et al., 2014; Iwouno, Ofoedu & Aniche, 2019).

Appearance, which also include but not limited to colour and absence of haze greatly affect beer perception. Similar to mouthfeel and colour of beer samples, the appearance (6.24 – 6.52) of rice beer samples was slightly liked probably because the rice malt beers appeared very slightly hazy compared to the commercial lager beer (8.61) which appeared almost brilliant in clarity. The variations in appearance could be due to differences in brewing technology adopted. Notably, the taste and aroma across the beer samples resembled ( $p > 0.05$ ), although the sensory scores indicated the taste and aroma of commercial lager beer as liked very much, whereas that of rice malt beer samples were liked moderately. Specifically, aroma and taste of beer is characterized by volatile compound profile (Marconi et al., 2017) influenced principally by yeast metabolism. The differences in taste and aroma of beer samples may occur with fermentation by-products, such as aroma-active esters, higher alcohols and aldehydes (He et al., 2014; Ferreira & Guido, 2018). The overall acceptance herein suggests sensory properties of beer might be affecting consumer liking, considering the commercial lager beer was liked very much by the panellists. Besides FARO 44 and NERICA 7 beer being liked moderately, the FARO 57 beer was slightly liked. Overall, the rice malt beer resembled in sensory profiling to the commercial lager beer in aroma and taste, but more flat in mouthfeel.

#### **4. CONCLUSIONS**

Characteristic changes in malt, wort and beer from different locally produced (Nigeria) rice varieties as influenced by varying malting conditions were investigated. The rice varieties

exhibited desirable gain quality characteristics and showed acceptable aptitude to be malted due to their germinative property of greater than 85 %. Malting conditions significantly influenced the CWE, HWE, DP, MC and TN of rice malt. Through peak FARO 44 ( $S_{18}G_3K_{55^\circ}$ ), FARO 57 ( $S_{30}G_2K_{50^\circ}$ ) and NERICA 7 ( $S_{24}G_3K_{55^\circ}$ ) malt outputs, the resulting wort produced promising pH, TSN, Brix, KI, FAN, DE, OE ranges and sugar profile similar to that of barley malt wort. Across varieties, the pH, TSN, Brix, KI, FAN, DE and OE in rice malt wort, and pH, colour, AE and turbidity in rice beer resembled ( $p>0.05$ ), but not so in ABV ( $p<0.05$ ). In addition, the rice malt beer, very slightly hazy, represented a pale yellow light lager. To obtain wort that makes an alcohol clear beer requires the addition of exogenous enzymes, particularly in the mashing of rice malts. Moreover, malting would improve hydrolysis, modify the starchy (rice) endosperm, which could allow adequate production of FAN, TSN and other fermentable extracts in wort. Besides the sensory profiling differing in appearance, the characteristic pale yellow rice malt beer resembled the commercial lager beer in aroma and taste, but more flat in mouthfeel. However, the overall acceptance suggest that rice malt beer from FARO 44 was preferred more amongst other rice malt beers, after the commercial lager beer. Malting conditions of current study appears very promising for commercial lager beer production since not all the variety is suitable for brewing, and therefore careful variety selection for optimized output is important. Further research is warranted on other locally available rice varieties as well as underutilized cereals for malting/brewing, which would target higher extract yield and clearer beer.

# **CONFLICT OF INTEREST STATEMENT**

Charles Odilichukwu R. Okpala is an Academic Editor of PeerJ.

# **AUTHOR CONTRIBUTIONS**

CEO, CQA, JOI and CDO conceived/conducted the study and prepared initial manuscript draft. CORO, and MK revised manuscript draft and strengthened the scientific interpretation. All authors contributed to the intellectual content and confirmed the final submitted version.

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# **CONSENT TO PARTICIPATE IN SENSORY ANALYSIS**

Specific to sensory evaluation of current work, oral consent was obtained from participants prior to their participation. Ethics approval was given by the internal ethics committee of the School of

676 Engineering and Engineering Technology, Federal University of Technology, Owerri, Imo State,  
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# Figure 1

Figure 1: Schematic overview of the experimental program.

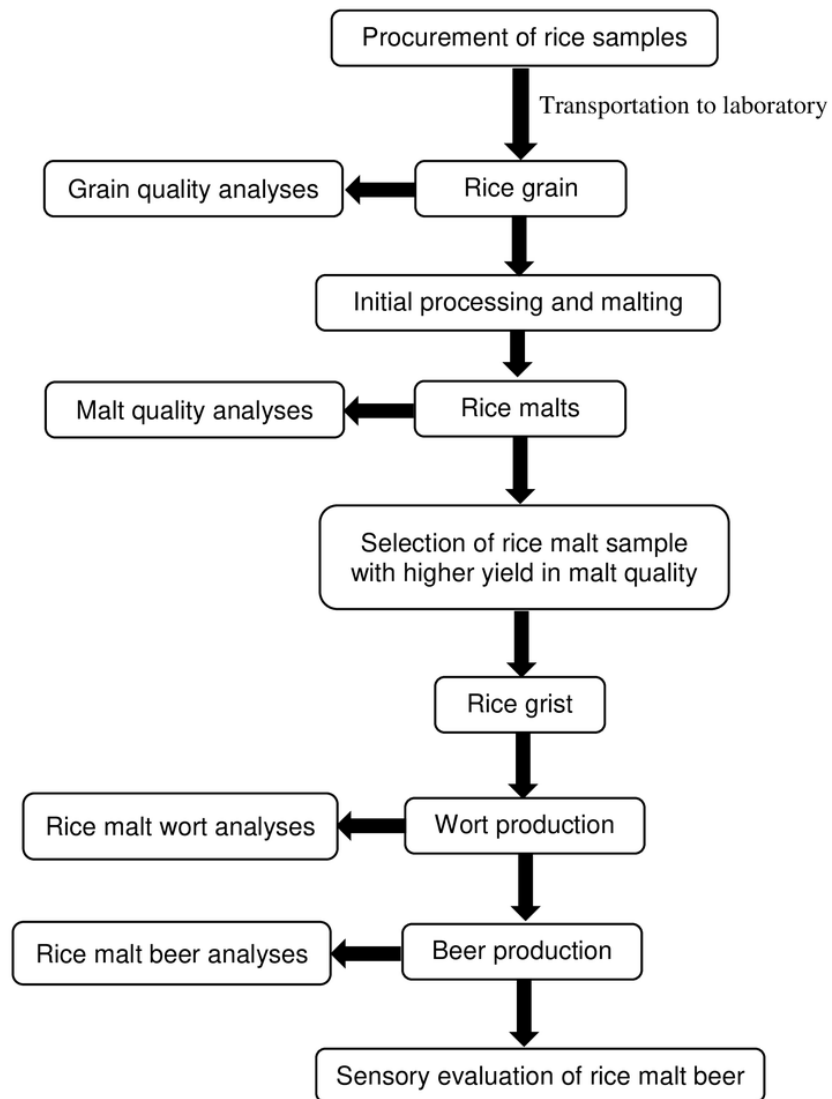


Figure 1: Schematic overview of the experimental program.

# Figure 2

Figure 2: Flow diagram for the production of rice malt wort



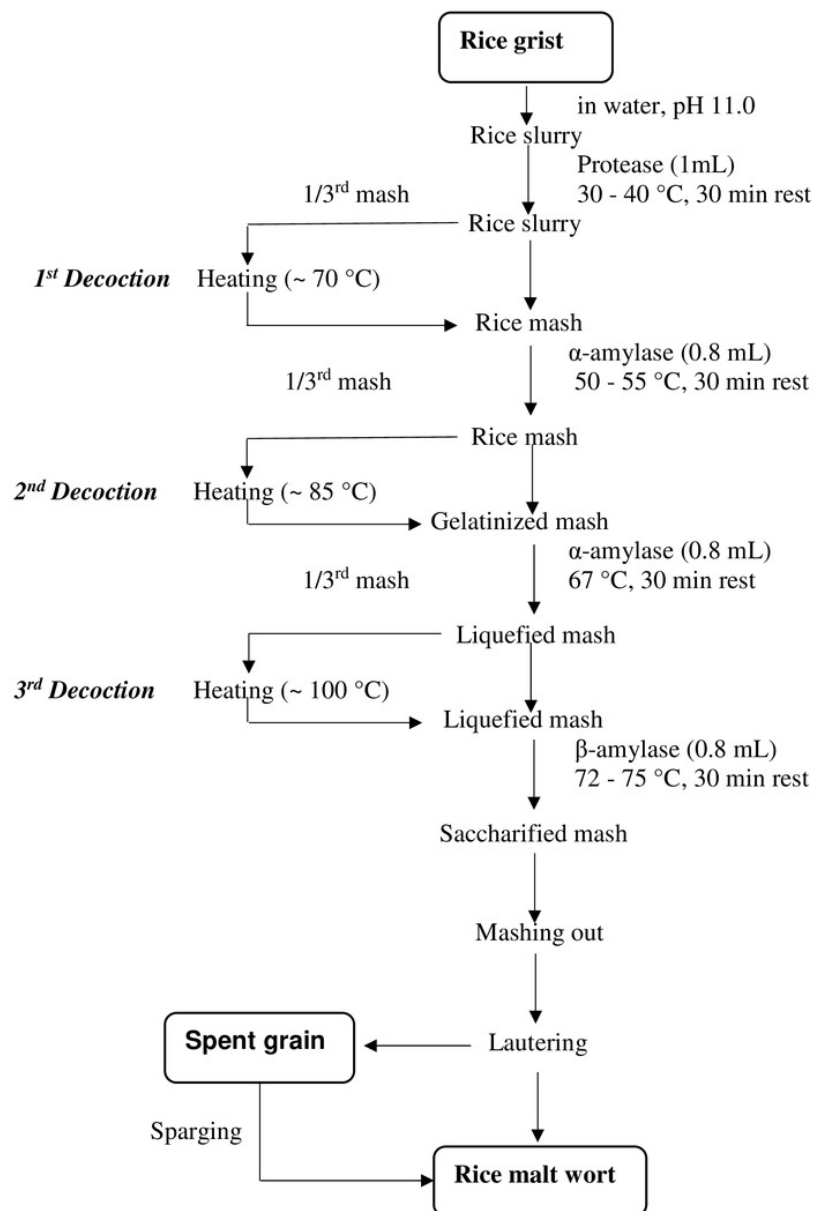


Figure 2: Flow diagram for the production of rice malt wort

**Table 1** (on next page)

Table 1: Malting characteristics and grain quality properties of rice varieties.

**Table 1: Malting characteristics and grain quality properties of rice varieties.**

SAMPLES	TCW (g)	GE (%)	GC (%)	DoS (%)
<b>FARO 44</b>	25.81 <sup>c</sup> ±0.01	86.50 <sup>c</sup> ±0.06	92.50 <sup>b</sup> ±0.14	55.00 <sup>a</sup> ±0.16
<b>FARO 57</b>	26.11 <sup>b</sup> ±0.16	93.50 <sup>b</sup> ±0.07	93.00 <sup>b</sup> ±0.00	50.98 <sup>b</sup> ±0.07
<b>NERICA 7</b>	27.01 <sup>a</sup> ±0.07	95.00 <sup>a</sup> ±0.98	95.50 <sup>a</sup> ±0.10	49.96 <sup>c</sup> ±0.09
<b>LSD</b>	<b>0.24</b>	<b>1.50</b>	<b>1.50</b>	<b>0.44</b>

*Values are the means of duplicate determinations (N=2)*

a,b,...means with the same superscript along a column for each parameter is not significantly different (P>0.05)

TCW = Thousand corn weight; GE = Germination energy; Germinative capacity; MY = Malt yield; ML = Malting loss; DoS = Degree of steeping

## Table 2 (on next page)

Table 2: Cold water extract (CWE) (g/100g) of rice malts subject to varying steeping durations, germination periods and kilning temperatures

**Table 2: Cold water extract (CWE) (g/100g) of rice malts subject to varying steeping durations, germination periods and kilning temperatures**

Malting conditions			Rice varieties		
Steeping duration (hours)	Germination period (days)	Kilning temperature			
		(°C)	FARO 44	FARO 57	NERICA 7
18	2	50	21.66 <sup>d</sup> ±0.03	19.43 <sup>c</sup> ±0.28	10.95 <sup>l</sup> ±0.01
		55	22.28 <sup>b</sup> ±0.06	14.39 <sup>j</sup> ±0.42	12.68 <sup>i</sup> ±0.04
	3	50	21.84 <sup>c</sup> ±0.10	13.99 <sup>k</sup> ±0.06	11.73 <sup>k</sup> ±0.06
		55	22.88 <sup>a</sup> ±0.13	11.44 <sup>m</sup> ±0.06	13.31 <sup>f</sup> ±0.07
	4	50	20.45 <sup>j</sup> ±0.08	16.51 <sup>h</sup> ±0.07	12.68 <sup>i</sup> ±0.06
		55	20.53 <sup>hi</sup> ±0.17	14.38 <sup>j</sup> ±0.11	20.25 <sup>c</sup> ±0.17
24	2	50	20.77 <sup>f</sup> ±0.14	20.58 <sup>b</sup> ±0.14	12.52 <sup>j</sup> ±0.08
		55	20.95 <sup>e</sup> ±0.14	15.17 <sup>i</sup> ±0.10	14.94 <sup>d</sup> ±0.10
	3	50	20.58 <sup>gh</sup> ±0.11	18.24 <sup>e</sup> ±0.10	12.52 <sup>j</sup> ±0.07
		55	20.76 <sup>f</sup> ±0.06	13.20 <sup>l</sup> ±0.04	23.16 <sup>a</sup> ±0.07
	4	50	19.81 <sup>l</sup> ±0.08	16.91 <sup>g</sup> ±0.07	12.93 <sup>h</sup> ±0.57
		55	20.49 <sup>ij</sup> ±0.08	17.18 <sup>f</sup> ±0.07	21.13 <sup>b</sup> ±0.08
30	2	50	18.50 <sup>n</sup> ±0.04	22.13 <sup>a</sup> ±0.06	13.32 <sup>f</sup> ±0.03
		55	19.72 <sup>m</sup> ±0.13	16.51 <sup>h</sup> ±0.11	17.19 <sup>g</sup> ±0.11
	3	50	19.61 <sup>k</sup> ±0.14	18.98 <sup>d</sup> ±0.13	13.50 <sup>f</sup> ±0.10
		55	20.58 <sup>g</sup> ±0.03	15.17 <sup>i</sup> ±0.03	14.54 <sup>d</sup> ±0.01
	4	50	18.49 <sup>n</sup> ±0.06	19.03 <sup>d</sup> ±0.06	13.69 <sup>f</sup> ±0.04
		55	20.46 <sup>ij</sup> ±0.08	16.51 <sup>h</sup> ±0.07	16.34 <sup>f</sup> ±0.07
LSD			0.27	0.59	0.45

*Values are the means of duplicate determinations (N=2)*

a,b,...means with the same superscript along a column for each rice variety is not significantly different (P>0.05)

# **Table 3**(on next page)

Table 3: Hot water extract (HWE) (°L/kg) of rice malts subject to varying steeping durations, germination periods and kilning temperatures

**Table 3: Hot water extract (HWE) (°L/kg) of rice malts subject to varying steeping durations, germination periods and kilning temperatures**

Malting conditions			Rice varieties		
Steeping duration (h)	Germination period (days)	Kilning temperature (°C)	FARO 44	FARO 57	NERICA 7
18	2	50	121.56 <sup>b</sup> ±0.48	103.05 <sup>h</sup> ±0.41	130.06 <sup>h</sup> ±0.54
		55	103.18 <sup>e</sup> ±1.02	103.18 <sup>gh</sup> ±0.99	182.10 <sup>b</sup> ±1.80
	3	50	103.18 <sup>e</sup> ±0.74	105.17 <sup>f</sup> ±0.75	163.71 <sup>e</sup> ±1.16
		55	136.56 <sup>a</sup> ±1.16	100.15 <sup>i</sup> ±0.88	182.10 <sup>b</sup> ±1.54
	4	50	106.22 <sup>d</sup> ±0.59	160.43 <sup>c</sup> ±0.91	121.41 <sup>k</sup> ±0.69
		55	115.56 <sup>c</sup> ±0.81	105.17 <sup>f</sup> ±0.74	163.90 <sup>e</sup> ±1.13
24	2	50	100.15 <sup>f</sup> ±1.13	106.22 <sup>e</sup> ±1.20	166.91 <sup>d</sup> ±1.90
		55	84.97 <sup>j</sup> ±0.83	106.22 <sup>e</sup> ±1.02	148.00 <sup>f</sup> ±1.47
	3	50	100.15 <sup>f</sup> ±0.17	106.22 <sup>e</sup> ±0.18	182.10 <sup>b</sup> ±0.31
		55	91.04 <sup>i</sup> ±0.44	103.18 <sup>gh</sup> ±0.51	206.48 <sup>a</sup> ±0.99
	4	50	84.97 <sup>j</sup> ±0.54	106.22 <sup>e</sup> ±0.68	182.10 <sup>b</sup> ±1.16
		55	106.18 <sup>d</sup> ±0.28	103.48 <sup>g</sup> ±0.28	133.70 <sup>i</sup> ±0.35
30	2	50	51.06 <sup>m</sup> ±0.33	170.18 <sup>a</sup> ±1.10	139.60 <sup>g</sup> ±0.91
		55	75.98 <sup>k</sup> ±0.24	136.56 <sup>d</sup> ±0.34	127.50 <sup>j</sup> ±0.41
	3	50	75.98 <sup>k</sup> ±0.65	166.91 <sup>b</sup> ±1.41	127.50 <sup>j</sup> ±1.08
		55	97.06 <sup>g</sup> ±0.55	106.22 <sup>e</sup> ±0.78	163.90 <sup>e</sup> ±0.93
	4	50	60.70 <sup>l</sup> ±0.21	106.02 <sup>e</sup> ±0.35	172.98 <sup>c</sup> ±0.59
		55	94.21 <sup>h</sup> ±0.62	103.08 <sup>h</sup> ±0.68	133.70 <sup>i</sup> ±0.89
LSD			0.49	0.30	1.19

*Values are the means of duplicate determinations (N=2)*

a,b,...means with the same superscript along a column for each rice variety is not significantly different (P>0.05)

# **Table 4**(on next page)

Table 4: Diastatic power (DP) (°L) of rice malts subject to varying steeping durations, germination periods and kilning temperatures



**Table 4: Diastatic power (DP) (°L) of rice malts subject to varying steeping durations, germination periods and kilning temperatures**

Malting conditions			Rice varieties		
Steeping duration (h)	Germination period (days)	Kilning temperature (°C)	FARO 44	FARO 57	NERICA 7
18	2	50	78.00 <sup>e</sup> ±0.74	63.00 <sup>f</sup> ±0.59	71.00 <sup>i</sup> ±0.66
		55	92.00 <sup>c</sup> ±0.59	22.00 <sup>n</sup> ±0.14	97.00 <sup>g</sup> ±0.61
	3	50	63.00 <sup>g</sup> ±0.28	50.00 <sup>i</sup> ±0.23	48.00 <sup>m</sup> ±0.21
		55	150.00 <sup>a</sup> ±0.23	38.00 <sup>l</sup> ±0.06	60.00 <sup>l</sup> ±0.10
	4	50	80.00 <sup>d</sup> ±0.37	37.00 <sup>l</sup> ±0.17	67.00 <sup>k</sup> ±0.30
		55	98.00 <sup>b</sup> ±0.42	26.00 <sup>m</sup> ±0.11	100.00 <sup>e</sup> ±0.44
24	2	50	43.00 <sup>l</sup> ±0.06	80.00 <sup>e</sup> ±0.11	98.00 <sup>f</sup> ±0.14
		55	63.00 <sup>f</sup> ±0.18	39.00 <sup>k</sup> ±0.11	120.00 <sup>c</sup> ±0.34
	3	50	50.00 <sup>j</sup> ±0.21	64.00 <sup>f</sup> ±0.27	60.00 <sup>l</sup> ±0.25
		55	52.00 <sup>i</sup> ±0.28	52.00 <sup>h</sup> ±0.28	143.00 <sup>a</sup> ±0.79
	4	50	44.00 <sup>k</sup> ±0.34	57.00 <sup>g</sup> ±0.44	60.00 <sup>l</sup> ±0.45
		55	57.00 <sup>h</sup> ±0.61	39.01 <sup>k</sup> ±0.41	101.00 <sup>e</sup> ±1.08
30	2	50	38.00 <sup>p</sup> ±0.15	148.00 <sup>a</sup> ±0.58	102.00 <sup>e</sup> ±0.41
		55	39.00 <sup>o</sup> ±0.38	43.00 <sup>j</sup> ±0.42	113.00 <sup>d</sup> ±1.12
	3	50	35.00 <sup>q</sup> ±0.25	135.00 <sup>b</sup> ±0.96	92.00 <sup>h</sup> ±0.65
		55	38.00 <sup>p</sup> ±0.32	98.08 <sup>c</sup> ±0.83	138.00 <sup>b</sup> ±1.17
	4	50	39.00 <sup>o</sup> ±0.23	92.00 <sup>d</sup> ±0.52	46.00 <sup>m</sup> ±0.25
		55	40.00 <sup>m</sup> ±0.24	43.00 <sup>j</sup> ±0.25	75.00 <sup>i</sup> ±0.45
LSD			0.73	0.98	1.63

*Values are the means of duplicate determinations (N=2)*

a,b,...means with the same superscript along a column for each rice variety is not significantly different (P>0.05)

# **Table 5**(on next page)

Table 5: Measured values of analysed of rice malt samples

**Table 5: Measured values of analysed of rice malt samples**

Samples	MY (%)	ML (%)	MC (g/100g)	TN (g/L)
<b>FARO 44</b>	92.65 <sup>a</sup> ±0.33	6.03 <sup>c</sup> ±0.62	5.52 <sup>b</sup> ±0.18	15.70 <sup>a</sup> ±0.05
<b>FARO 57</b>	90.65 <sup>b</sup> ±0.95	8.05 <sup>b</sup> ±0.38	5.19 <sup>c</sup> ±0.13	14.30 <sup>b</sup> ±0.17
<b>NERICA 7</b>	87.11 <sup>c</sup> ±0.74	10.80 <sup>a</sup> ±0.25	6.43 <sup>a</sup> ± 0.14	13.10 <sup>c</sup> ±0.16
<b>LSD</b>	<b>0.34</b>	<b>0.05</b>	<b>0.28</b>	<b>0.24</b>

*Values are the means of duplicate determinations (N=2)*

a,b,...means with the same superscript along a column for each parameter is not significantly different (P>0.05)

# **Table 6**(on next page)

Table 6: Sugar profile of rice malt wort

1 **Table 6: Sugar profile of rice malt wort**

SAMPLES	Maltotriose (%)	Glucose (%)	Maltose (%)	Maltotetraose (%)	Sucrose (%)	Raffinose (%)
<b>FARO 44</b>	12.26 <sup>c</sup> ±0.28	11.23 <sup>a</sup> ±0.16	14.63 <sup>b</sup> ±0.11	0.63 <sup>a</sup> ±0.04	2.44 <sup>b</sup> ±0.10	0.07 <sup>a</sup> ±0.00
<b>FARO57</b>	13.25 <sup>b</sup> ±0.14	11.63 <sup>a</sup> ±0.71	15.34 <sup>a</sup> ±0.08	0.53 <sup>b</sup> ±0.03	2.32 <sup>c</sup> ±0.03	0.05 <sup>b</sup> ±0.00
<b>NERICA 7</b>	16.40 <sup>a</sup> ±0.07	10.84 <sup>b</sup> ±0.06	15.03 <sup>a</sup> ±0.04	0.44 <sup>c</sup> ±0.06	2.83 <sup>a</sup> ±0.08	0.06 <sup>ab</sup> ±0.00
<b>LSD</b>	<b>0.03</b>	<b>0.02</b>	<b>0.03</b>	<b>0.03</b>	<b>0.03</b>	<b>0.01</b>

2 *Values are the means of duplicate determinations (N=2)*

3 a,b....means with the same superscript along a column for each parameter is not significantly different (P>0.05)

4

# **Table 7** (on next page)

Table 7: Measured values of analysed rice malt wort samples

**Table 7: Measured values of analysed rice malt wort samples**

Samples	pH	TSN (g/L)	Brix (g/100g)	KI (%)	FAN (mg/L)	DE (g/100g)	OE (g/100g)
<b>FARO 44</b>	5.40 <sup>a</sup> ± 0.38	5.40 <sup>a</sup> ±0.00	14.65 <sup>b</sup> ±0.07	34.39 <sup>c</sup> ±0.13	108.56 <sup>c</sup> ±0.08	39.00 <sup>a</sup> ±1.42	11.15 <sup>a</sup> ±0.05
<b>FARO 57</b>	5.30 <sup>a</sup> ±0.17	5.60 <sup>a</sup> ±0.00	16.36 <sup>a</sup> ±0.42	39.16 <sup>b</sup> ±0.09	112.23 <sup>b</sup> ±0.28	40.00 <sup>a</sup> ±0.82	12.66 <sup>a</sup> ±0.04
<b>NERICA 7</b>	5.30 <sup>a</sup> ±0.10	5.80 <sup>a</sup> ±0.00	13.88 <sup>c</sup> ±0.11	44.27 <sup>a</sup> ±0.28	117.34 <sup>a</sup> ±0.06	37.00 <sup>a</sup> ±0.01	9.68 <sup>a</sup> ±0.07
<b>LSD</b>	<b>NS</b>	<b>NS</b>	<b>0.58</b>	<b>3.20</b>	<b>4.32</b>	<b>NS</b>	<b>NS</b>

*Values are the means of duplicate determinations (N=2)*

a,b,...means with the same superscript along a column for each parameter is not significantly different (P>0.05)

TSN = Total soluble nitrogen; KI = Kolbach index; FAN = Free amino nitrogen;

DE = Dextrose equivalent; and OE= Original extract

# **Table 8**(on next page)

Table 8: Measured values analysed rice malt beer samples



**Table 8: Measured values analysed rice malt beer samples**

Samples	pH	Colour (°EBC)	AE (g/100g)	Alcohol content (% ABV)	Turbidity (NTU)
<b>FARO 44</b>	3.80 <sup>a</sup> ±0.44	3.70 <sup>a</sup> ±0.16	4.59 <sup>a</sup> ±0.74	3.54 <sup>b</sup> ±0.06	5.30 <sup>a</sup> ±0.01
<b>FARO 57</b>	3.90 <sup>a</sup> ±0.59	3.73 <sup>a</sup> ±0.71	4.57 <sup>a</sup> ±1.07	4.13 <sup>a</sup> ±0.18	4.80 <sup>a</sup> ±0.17
<b>NERICA 7</b>	3.80 <sup>a</sup> ±0.10	3.20 <sup>a</sup> ±0.42	4.93 <sup>a</sup> ±0.54	2.82 <sup>c</sup> ±0.50	4.30 <sup>a</sup> ±0.21
<b>LSD</b>	<b>NS</b>	<b>NS</b>	<b>NS</b>	<b>0.39</b>	<b>NS</b>

*Values are the means of duplicate determinations (N=2)*

a,b,...means with the same superscript along a column for each parameter is not significantly different (P>0.05)

AE = Apparent extract; ABV = Alcohol by volume

# **Table 9**(on next page)

Table 9: Sensory attributes of rice malt beer of different varieties.

1 **Table 9: Sensory attributes of rice malt beer of different varieties.**

<b>SAMPLES</b>	<b>Colour</b>	<b>Taste</b>	<b>Aroma</b>	<b>Mouthfeel</b>	<b>Appearance</b>	<b>Overall acceptability</b>
<b>Commercial lager beer</b>	8.71 <sup>a</sup> ±0.55	8.19 <sup>a</sup> ±0.13	7.99 <sup>a</sup> ±0.51	8.51 <sup>a</sup> ±0.25	8.61 <sup>a</sup> ±0.45	8.40 <sup>a</sup> ±0.38
<b>FARO 44</b>	6.91 <sup>b</sup> ±0.33	7.87 <sup>b</sup> ±0.32	7.81 <sup>a</sup> ±0.33	6.96 <sup>b</sup> ±0.32	6.52 <sup>b</sup> ±0.32	7.21 <sup>b</sup> ±0.30
<b>FARO 57</b>	6.66 <sup>b</sup> ±0.13	7.69 <sup>b</sup> ±0.21	7.54 <sup>a</sup> ±0.16	6.57 <sup>b</sup> ±0.41	6.24 <sup>b</sup> ±0.23	6.94 <sup>b</sup> ±0.08
<b>NERICA 7</b>	6.87 <sup>b</sup> ±0.25	7.82 <sup>b</sup> ±0.10	7.80 <sup>a</sup> ±0.51	6.76 <sup>b</sup> ±0.22	6.41 <sup>b</sup> ±0.23	7.13 <sup>b</sup> ±0.24
<b>LSD</b>	<b>0.85</b>	<b>NS</b>	<b>NS</b>	<b>1.22</b>	<b>0.93</b>	<b>0.56</b>

2 *Values are the means of duplicate determinations (N=2)*

3 a,b,...means with the same superscript along a column for each parameter is not significantly different (P>0.05)

4