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Biochemically assisted rice whitening for improving head rice yield

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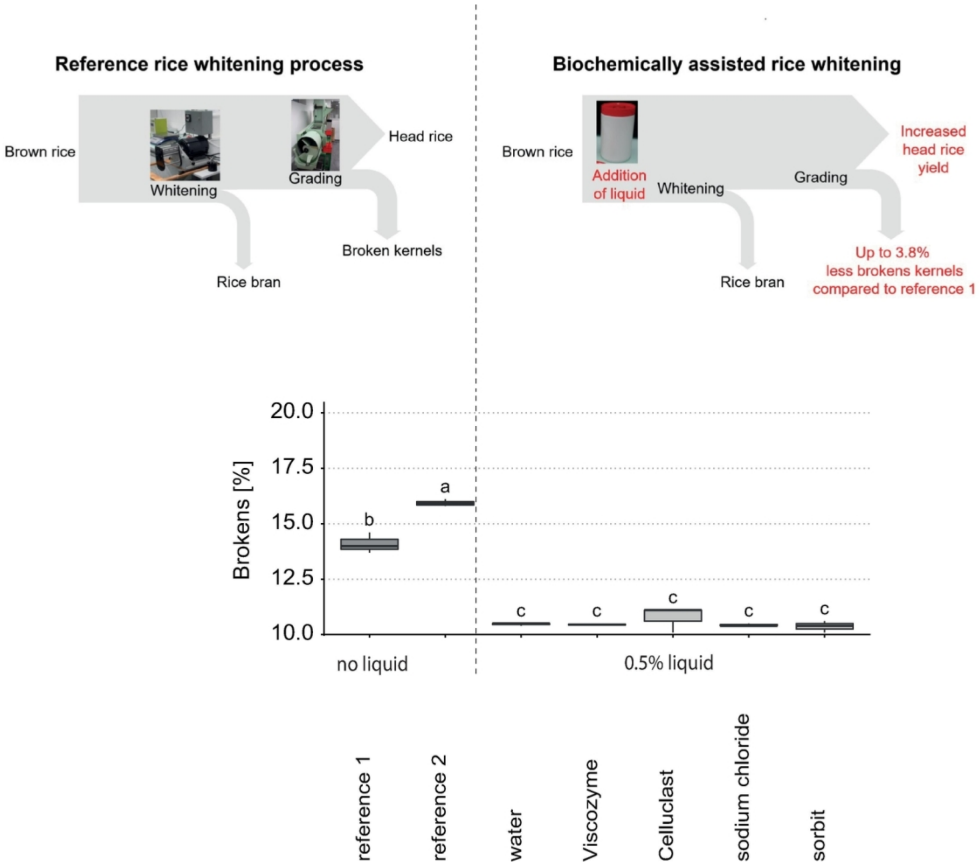

Graphical Abstract

139x119mm (300 x 300 DPI)

Title: Biochemically assisted rice whitening for improving head rice yield

Short running title: Biochemically assisted rice whitening

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Abstract

The maximum attainable head rice yield in conventional long grain rice milling is approximately 64 %, with around 15 % being lost as a result of broken rice kernels. The primary objective of this project was, therefore, to improve the milling yield. To achieve this goal, biochemically assisted whitening processes involving the application of different aqueous solutions were evaluated. Head rice yield was increased for all tested liquids (3.3 to 3.8 % depending on liquid) for Gladio-type brown rice treated with 0.5 % liquid prior to whitening to 40 Kett using a lab-scale horizontal friction-type McGill whitener. However, the moistening led to increased caking in the McGill milling chamber. In comparative trials, the use of moistening solutions containing enzymes, sorbit or sodium chloride instead of pure water, delivered a slightly, but nevertheless, significantly higher degree of whiteness directly after milling while it did not result in a significant reduction in the number of broken kernels. Since average head rice yield has a 43% higher commercial value than broken kernels, the 3.6% improvement in milling yield achieved by adding 0.5% water, would result in an estimated increase in profit for a 7.5 t/h rice mill of 0.83 %.

Keywords

Rice whitening, head rice yield, enzymes, processability, profit increase, ecologic sustainability.

Abbreviations

TGA	thermogravimetric analysis
SEM	scanning electron microscope

Practical Applications

Biochemically assisted rice whitening for improving head rice yield

Rice as a global staple food bears a critical role in human nutrition. At the same time, the quality of milled rice is a key buying and price criterion in rice-consuming countries. One key quality criterion is the number of brokens in rice. Hence, it is critical for rice millers to minimise the degree of broken kernels. Biochemically assisted rice whitening for improving head rice yield is a combined biochemical and physical method to facilitate bran removal from brown rice. The main aim of the present study was to investigate the effect of biochemically assisted rice whitening on the number of brokens and to assess potential technological challenges resulting from the liquid addition.

Introduction

Rice (*Oryza sativa* L.) and its three relevant subspecies, *Indica*, *Japonica* and *Javanica,* all have similar grain structures of a seed with testa, nucellus, embryo and endosperm, covered with a tightly adhered pericarp (bran layers) and protected by a silicium-rich hull (Bechtel and Pomeranz 1978; Bienvenido and Tuaño, 2019).

During paddy rice milling, the inedible hull is removed by rubber rollers to produce brown rice. The subsequent whitening process involves 2 – 4 steps, depending on the type of rice being processed, before up to two polishing steps are performed in order to obtain glossy white rice. (Eyarkai Nambi et al., 2017, Mueller-Fischer 2012)

The whitening process removes the germ and bran layers from the brown rice by rubbing the kernels between an abrasive stone and a screen. The rice is then polished by friction between the kernels, at the same time a water mist is sprayed onto the rice to allow the smallest starch particles to adhere to the kernel surface, thus resulting in a glossy finish (Mueller-Fischer

2012). However, both whitening and polishing cause some kernels to break, with multiple factors contributing to the extent of crack formation and grain breakage. Such factors include, among others: (i) rice cultivars that exhibit different sensitivities to breakage, (ii) distribution of rice kernel dimensions, leading to the thickest and thinnest kernels being more likely to break, (iii) environmental conditions during growth and harvest, for example high growing temperatures that can disrupt starch synthesis resulting in chalkiness, (iv) chalkiness itself, (v) changes in rice moisture content (values of 14 - 16% deliver the highest resistance to breakage,) (vi) drying the paddy without proper tempering, (vii) parboiling to heal fissures, and (viii) type and degree of rice processing . (Banaszek and Siebenmorgen 2013; Bao, 2019; Bautista and Siebenmorgen 2005; Bhattacharya 2011; Bienvenido and Tuaño, 2019; Corrêa et al. 2007;; Firouzi et al., 2017; Zhou et al. 2015)

Apart from a water mist added during rice polishing to achieve enhanced glossiness, no water is added to the rice kernel in state-of-the-art milling. Several authors have described enzymatic pre-treatment of rice before whitening or polishing. However, all of the treatments resulted in a significant impact on subsequent processing, rice quality and/or storability. Arora et al. (2007) found that spraying Basmati rice with cellulase had a positive effect on breakage rates (3.23 to 4.58 % brokens after treatment compared to 4.72% brokens in untreated Basmati), but encountered oxidative issues during storage. Das et al. (2008a; 2008b) soaked rice with xylanase and cellulase to selectively degrade the bran layers, as an alternative to physical polishing, before steaming the rice to deactivate the enzymes. Hay et al. (2006) describe laboratory scale maceration of aleurone and subaleurone cells on the inner surface of the isolated caryopsis coat when exposed to Pectolyase Y-23 to separate the tissues. Similar effects have been established for pulse hulling where an enzymatic pre-treatment allows pulses, such as pigeon peas, to be separated into intact splits (Sangani et al. 2010).

In conventional rice milling, out of a total of 64% polished rice, only 49% is termed head rice, since 15% of the kernels are broken and of lower economic value. A mass balance for the entire rice milling process, adapted from Mueller-Fischer (2012) is depicted in Fig. 1. The whitening process was adapted to include biochemically assisted bran removal through the addition of an aqueous solution, such as water (optionally containing enzymes, sodium chloride or sorbit), immediately before being processed in a laboratory scale whitener. The underlying hypothesis was that a moistening step will allow the bran layers to be rubbed off more gently as is commonly observed in conditioning of wheat before milling (Kweon et al. 2009). Increasing the milling yield by decreasing the number of broken kernels during whitening is therefore the primary objective of this project.

Materials and Methods

Brown rice (*Oryza sativa L*, subspecies *Indica*, type Gladio, harvest 2008, Italy) was whitened in a lab scale McGill rice whitener (McGill Miller No. 3, Rapsco, USA) using various protocols summarized in Table 1:

(1) In reference process 1 that simulated conventional rice whitening at the laboratory scale, 500 g brown rice was whitened for 15 s by applying a milling weight of 10 lbs. The milling time and milling weight were optimised in preliminary trials that tested weights of between 5 and 15 lbs and milling times between 5 and 30 s. The combination of 15 s milling at 10 lbs was found to maximise head rice yield and achieve the desired whiteness of 40 Kett.

(2) For reference process 2, a two-step milling process was implemented to simulate two whitening passages, 700 g brown rice was first whitened for 5 s using a milling weight of 1 lb and then 500 g head rice from the pre-milled batch was processed for 15 s with a milling weight of 10 lbs. In between the two milling steps, the rice was separated from the bran using a lab sifter (Type AS 400 control, Retsch GmbH, Germany, sieve mesh size 1.12 mm) at 350 rpm for 1 min and then the head rice was separated from the broken kernels using a lab trieur

(Type Mini-Petkus, Röber GmbH, Agrartechnik und Maschinenbau, Germany) at 50 Hz, first using a 2 mm round holed vibrating screen, then a trieur sleeve with 5.5 mm wide indentations, both were performed without aspiration and at the minimum feed rate. Unlike in reference process 1, the pre-milling in reference process 2 opens up the bran layers in order to allow the application of active agents.

(3) Biochemically assisted rice whitening was performed with and without pre-whitening (1 lb / 5 s), followed by a moistening step and concluded by an end-whitening step for 15 s with a milling weight of either 10 or 1 lb. Tap water (pH 7.6, water hardness 21.4 °d with 117.1 mg/l Ca and 21.5 mg/l Mg, electrical conductivity 624.6 microSiem/cm), Viscozyme® L (dosage 0.3% based on dry matter, declared activity: beta-glucanase (endo-1,3(4)-), Novozymes A/S, Denmark), Celluclast® 1.5L (dosage 0.3% based on dry matter, declared activity: cellulase, Novozymes A/S, Denmark), a 5% sodium chloride solution in water (NaCl, Merck KGaA, Germany) or a 5% sorbit solution in water (d (-) sorbit powder, Merck KGaA, Germany) were used as moistening solutions. Either 700 g un-milled or 500 g of pre-milled Gladio brown head rice was added to a plastic container, then either 0.5 or 1.0 % of 18 °C warm liquid was added using an electronic repetitive pipette. The container was then closed and shaken for 1 minute.

Room conditions were adjusted to 20 °C and 43 % relative humidity using an air humidifier (type Century 210311, Walter Meier (Klima Schweiz) AG, Switzerland) for all of the trials in order to obtain an air moisture content that matched the moisture of the rice (55% rH corresponding to 12% moisture in kernel, based on unpublished data from Bühler AG), thus preventing sorption at the rice surface upon contact with air to minimize inter-kernel stress.

All trials were performed in triplicate on three separate days.

To assess the moisture content of the rice kernels, thermogravimetric analysis (TGA 701, Leco Instrumente GmbH, Germany) was performed in triplicate at 105 °C (48 h for entire grains and 24 h for milled samples) to obtain mass balances throughout the process steps. The initial moisture content of Gladio brown rice was 12.88 ± 0.02% when measured by thermogravimetric analysis.

The whiteness of the rice was measured with a type C-300 digital whiteness meter (Kett, USA) working in reflective mode, with a measuring range of 5 – 70 Kett and an accuracy of 0.1 Kett. All analyses were performed in triplicate.

To assess the impact of whitening on bran lipids, sample particles were dispersed with a brush onto C-Tape on scanning electron microscope (SEM) object holders. Subsequently, compressed air was used to remove loose particles adhering to the surfaces of the samples and the SEM object holder. Prior to examination using the SEM (Zeiss, type DSM962, Germany) all samples were sputtered with gold.

Head rice and broken kernels were counted by hand based on standardised images according to industry standards, i.e. grains > ¾ of the original average length counted as head rice and < ¾ of the original average length counted as broken kernels.

Statistical analysis was performed by a Shapiro-Wilk normality test and a Bartlett test of homogeneity of variances (alpha = 5%) to reject the zero hypothesis and, thus, ensure the applicability of an analysis of variance (ANOVA). ANOVA showed highly significant differences ($p<0.01$). A Post-hoc Tukey honest significant difference test was then applied, with significantly different results indicated by different letters in the graphs shown in Figs. 2, 3 and 5.

The relative and absolute attainable increase in profit per year for each percent of additional head rice yield was computed using the following boundary conditions: (i) a rice mill with a throughput of 7.5 t/h paddy rice corresponding to 6.0 t/h brown rice, (ii) a utilisation capacity of 24 h/d for 300 d/y, (iii) operational costs including energy consumption, cleaning, sanitation etc. were assumed to be not affected by the biochemically assisted whitening process, (iv) 14 % rice moisture content with 86 % dry matter, (v) broken kernels were assumed to be 15 % (calculated on paddy rice basis), 19 % (on brown rice basis) and 22 % (on white rice basis), (vi) cost of moistening liquids were assumed to be negligible with the exception of enzymes which were calculated for Viscozyme to be 32.73 US$/l, (vii) a head rice price for higher quality Indica rice of 492 US$ in Thailand and 580 US$ in the US (EST: FAO Rice Price Update, accessed 27.11.2020), (vii) a broken kernel price of 70% of the head rice price was assumed (average range between 60 – 80% according to Siebenmorgen et al. (2008)).

Results and Discussion

A comparison of the effect on broken kernels and whiteness of a one-step and two-step whitening process without moistening (reference 1 and reference 2) and a process with an additional moistening step with water, Viscozyme or Celluclast between the pre-whitening and end-whitening processes is shown in Figure 2.

The percentages of broken kernels in all of the biochemically assisted rice whitening trials and in reference 2, which mimicked biochemically assisted rice whitening without moistening, were slightly but significantly higher than reference 1. No significant differences in broken kernels were observed between the different biochemically assisted rice whitening approaches, irrespective of the amount (0.5 or 1.0% moisture) or type of moistening solution (water, Viscozyme or Celluclast) added. Reference 1 led to a higher degree of whiteness (40.9 ± 0.37 Kett) than reference 2 (39.7 ± 0.41 Kett). All of the biochemically assisted rice whitening approaches led to significantly whiter rice than references 1 and 2. Furthermore, the different liquids had no observable effect on whiteness, nevertheless an addition of 1.0 instead of 0.5% liquid resulted in significantly higher whiteness for all of the liquids (0.5% water: 43.1 ± 0.41 Kett, 1.0% water: 44.0 ± 0.13 Kett, 0.5% Viscozyme: 42.8 ± 0.21 Kett, 1.0% Viscozyme: 43.7 ± 0.38 Kett, 0.5% Celluclast: 43.1 ± 0.27 Kett, 1.0% Celluclast: 43.7 ± 0.15 Kett).

The explanation why reference 2, with the two-step milling approach, led to slightly lower whiteness than reference 1can be found in the amount of bran removed: reference 1 led to a removal of 8.6 ± 0.14% bran, reference 2 to 4.1 ± 0.17%. No clear explanation was found as to why the total removal of bran in reference 2 was lower despite the fact that the combined mechanical energy input was slightly higher. The negative effect of adding a moistening liquid on the number of broken kernels could be attributed to resulting moisture differences within the kernel that lead to internal stress and make the kernel susceptible to breakage. This phenomenon is well known from rice drying, where moisture gradients are known to have a severe impact on breakage levels due to moisture stress attributable to the state of starch (Bhattacharya, 2011). The addition of liquids to rice raises the water content in the surface layers, which as a consequence may be just in the rubbery state based on the state diagram shown in Steiger et al. (2014) and assuming that temperatures during whitening raise significantly, however the kernel core remains in its glassy state (Conde-Petit 2001). The resulting differential stresses within the grains cause grain fissuring (Cnossen and Siebenmorgen 2000; Perdon et al. 2000). This theory needs to be proven but temperature measurements of the rice surface during whitening were not possible as the McGill rice whitener is a closed system.

In contrast, the addition of liquid had a positive effect on whiteness. Moistening during polishing is well-known to improve the visual perception of kernels and a similar effect might play a role in whitening. This is attributed to an enhanced adherence of loose starch particles to the rice kernel surface and can be seen by a reduction in total solids in cooking water. However, scientific studies on this topic are rare. The only available study that tested the effect of adding water during polishing found that adding 0.5 % water led to significantly enhanced whiteness of the resulting polished rice (Lee et al. 1992).

It was observed that the addition of liquid before end whitening led to caking in the whitener, i.e. rice kernels and abraded bran formed a compact mass and stuck to the inner surfaces of the whitener. As the effect was more pronounced when adding 1.0% than 0.5% moistening liquid (7% of the original material stuck to walls of whitener with the addition of 1.0% liquid versus 3% for 0.5% liquid) and since caking is critical in industrial rice milling, moisture addition was limited to 0.5% in the follow-up trials. Furthermore, since the biochemically assisted rice whitening resulted in whiteness that was higher than the desired 40 Kett in all trials (42.8 – 44.0), a reduction in whitening severity was tested: milling weight was reduced to 1 lb and pre-milling skipped in some trials. The results of these approaches are shown in Figure 3.

The aim of testing more gentle whitening parameters was to reach a whiteness of 40 Kett and then select the approach that resulted in the fewest broken kernels. Hence, all of the biochemically assisted rice whitening approaches milled in two steps and using 10 lbs for 15 s in the end-whitening step were ruled out as they significantly differ from both reference 1 and 2 and result in an excessive degree of whiteness. Biochemically assisted rice whitening with 0.5% water addition whitened in two steps with an end-whitening at 1 lb for 15 s delivered whiteness that was comparable to reference 2. The trials with 0.5% Viscozyme or Celluclast milled in one step at 1 lb for 15 s also delivered similar results, while two-step milling after the addition of an enzyme solution with an end-whitening at 1 lb for 15 s resulted in a higher whiteness than reference 1. The whiteness of the samples that had 0.5% water added and underwent only one milling step at 1 lb for 15 s was insufficient (39.0 ± 0.3 Kett instead of 40.0 Kett). All of the samples that received 0.5 % liquid and were milled in one step using a low milling weight of 1 lb for 15 s delivered a significant reduction in broken kernels from 14.1±0.37 and 15.9±0.12 % (reference 1 and 2, respectively) to 10.5±0.05, 10.3±0.26% and 10.8±0.47 % for water, Viscozyme and Celluclast, respectively. Since the Kett value of the water sample was 39.0 and, thus, slightly too low, it was only possible to define the setup as optimal for the samples that had 0.5% Viscozyme and Celluclast added and were milled in one step (1 lb for 15 s). It is hypothesised that adding a liquid improves bran removal by reducing adherence between the endosperm and the bran, similar to both pulse hulling (Sangani et al., 2010) and rice milling (Arora et al. 2007). As a consequence, milling weight could be reduced and the desired whiteness still achieved, leading to a reduction in broken kernels due to lower mechanical stress.

A tendendy to caking was again observed for all tested liquids. Additional SEM analyses of bran build-up were performed to determine whether the addition of liquid during whitening resulted in an increased availability of bran oil, resulting in more caking due to smearing, which sometimes occurs with bran from parboiled rice (Raghavendra Rao et al. 1967). A further exacerbation by enzymatical disruption of the cell walls compared to pure water can be precluded based on the percentage of caking that was measured (2.9, 1.6 and 1.7% of caking for water, Celluclast and Viscozyme, respectively). SEM images of (i) sticky bran from parboiled rice, (ii) conventionally milled rice produced in the lab-whitener and (iii) a representative bran sample produced by the biochemically assisted rice whitening process (exact setup: no pre-whitening, 0.5 % water, milling weight 1 lb, milling time 15 s) are depicted in Fig. 4. The images show that a film covers the bran of the parboiled rice while this is not the case after conventional milling or biochemically assisted rice whitening. This finding suggests that caking is not caused by a liquefying of lipids during whitening.

A detailed mass balance calculation was performed for all of the tested whitening methods to understand whether a change in moisture distribution over the milling fractions caused by the addition of liquids could explain the observed increase in caking. The mass balances of reference 2 and the two-step biochemically assisted rice whitening process with the addition of 1% water, a rest period of 1 minute, and end whitening at 10 lbs for 15 s are discussed as examples (see supplementary figures S1 and S2). As some of the measurements (caking) were analyzed in triplicate for one sample only, tendencies will be discussed. The initial moisture content of the pre-whitened rice samples were 13.02 and 12.98 % for reference 2 and the biochemically assisted rice whitening process, respectively. In reference 2, the following moisture contents were found after end-whitening: 13.0 % in rice, 11.6 % in caking and 9.7 % in bran. In comparison, the following moisture contents were found after end-whitening for the biochemically assisted rice whitening process with 1% water added,: 13.3 % in rice, 13.9 % in caking and 12.1 % in bran. The added moisture seems to mainly remains in the bran layers and does not reach the endosperm, which is important for rice storage. The findings further suggest that caking is at least to some extent caused by the higher moisture content in the bran layers which contributes to its stickiness.

Further trials applying one-step milling at optimal milling conditions of 1 lb for 15 s were performed with two additional liquids to understand whether the increased whiteness after milling with Viscozyme and Celluclast instead of water was caused by the enzymes or the additives which are part of the enzyme preparations, i.e. sodium chloride (in Celluclast and Viscozyme) and sorbit (in Celluclast).

Figure 5 shows that the application of pure water in biochemically assisted rice whitening led to significantly lower whiteness than both reference milling processes (reference 1: 40.9 ± 0.3 Kett, reference 2: 39.7 ± 0.4 Kett, water: 39.0 ± 0.3 Kett). In addition, all of the tested additives (enzymes, sorbit, sodium chloride) slightly but significantly increased whiteness compared to pure water (water: 39.0 ± 0.3 Kett , Viscozyme: 39.6 ± 0.3 Kett, Celluclast: 39.7 ± 0.1 Kett, sodium chloride: 40.0 ± 0.2 Kett, sorbit: 40.1 ± 0.3 Kett). One reason for the differences in whiteness might be the hygroscopicity of the two tested stabilizing agents used in the enzyme solutions, i.e. sodium chloride and sorbit. As a consequence of the higher uptake of sodium chloride or sorbit in the near surface layers, surface moisture might be higher directly after treatment but reduces once the moisture gradient within the kernel has been dispelled This might either lead to a further increase in whiteness over time caused by a less dense surface which, similar to a foam, can be expected to reflect light differently due to reflection and refraction effects (Tufaile et al. 2014) or to a decrease if the higher whiteness is caused by a swelling of the surface layers resulting in an apparent brightening of the kernels. To follow up, rice kernel whiteness was tested again after 6 weeks of storage. Whiteness increased for all samples including the references. The differences in whiteness were 1.8 Kett for reference 1, 2.8 Kett for water, 1.7 Kett for both Viscozyme and Celluclast, 1.4 Kett for the sorbit solution and 1.5 Kett for the sodium chloride solution. While the increase in whiteness of the samples treated with additives might be an indication in support of the theory of a higher moisture in surface near layers upon the application of hydrophobic additives before milling, the comparably higher increase in whiteness over time of the water treated sample contradicts the theory. Additional analyses would, thus, be necessary to understand the effect of the hydrophobic additives on the whiteness after milling. Further, the observation that applying pure water as the moistening liquid resulted in comparable whiteness levels after 6 weeks storage is of special practical importance.

In terms of broken kernels, all of the moistening liquids resulted in a significant reduction in broken kernels (14.1% and 15.9% for reference 1 and 2 compared to 10.5, 10.3, 10.8, 10.4, 10.4 for water, Viscozyme, Celluclast, sodium chloride and sorbit). The highest reduction in brokens was achieved using Viscozyme (3.8% reduction) when comparing to reference 1. The comparison of results for different liquids did not reveal a significant impact on the number of brokens and show that the addition of enzymes provides no advantage over the addition of liquids containing only sodium chloride or sorbit with respect to brokens nor over the trials applying pure water. It is likely that the enzymes did not have enough time to act, since the samples were whitened after only 1 minute of contact with the enzyme solution. The degree of reduction in brokens seems higher than findings by Arora et al. (2007) suggest where brokens in Basmati were reduced from 4.72% to between 3.23 and 4.58% after enzymatic treatment. In relative numbers, the maximally achieved reductions are however comparable, i.e. 31.6% relative reduction in brokens in Arora et al. (2007) compared to 35.2% relative reduction in own results. Das et al. (2008b) showed in SEM images that the application of cellulase and xylanase enzymes on rice brown rice led to a thinning of the outer bran layers while the effect of enzymatic treatment on the ease of physical whitening was not tested.

In consequence, the results of the water treated sample with a reduction of 3.6% compared to the industrially relevant reference 1 is of special economic importance as no additional material costs are generated nor a declaration of additives has to be taken into account.
Based on the overall findings, the number of broken kernels can be significantly reduced if 0.5% of any of the tested liquids is added. The biochemically assisted rice whitening process is seen as a promising process option and the effect on milling economics has also been calculated. Since pure water led to comparable effects with respect to brokens and, after storage, with respect to whiteness, the addition of enzymes was not taken into account and instead the calculations were made for water only. The resulting profitability per 1% additional head rice yield is 0.23 % based on an average price for broken rice of 70% of the price of head rice (Siebenmorgen et al. 2008). In other words, for a rice mill with a mean throughput of 7.5 t paddy rice per hour run for 24 h and 300 d/y, each additional percentage of head rice yield will result in an additional yearly profit of 46’547 US$, based on Thai premium Indica rice sold at 492 US$ per ton of head rice or 54’873 US$/y for US premium Indica rice sold at 580 US$ per ton (EST: FAO Rice Price Update, accessed 27.11.2020). While caking might lead to additional costs for cleaning, the reduced energy need during whiteness would further improve the business case. Neither of these effects were considered in the current calculation, as additional trials would be necessary to quantify the overall cost of additional cleaning and the costs saved through reduced energy usage.

Conclusions and outlook

Biochemically assisted rice whitening with a moistening step was proven to be an effective measure to enhance head rice yield. Comparison of different liquids showed that enzymes did not have the expected effect, which can be attributed to the very limited contact time before whitening. The fact that pure water, simple sodium chloride or sorbit solutions achieve the same effect on milling yield and, after 6 weeks storage time, on whiteness as the tested enzyme solutions is seen as positive: high consumer acceptance of especially water or sodium chloride is expected while reactions to enzymes might be ambivalent. The maximum achieved increase in head rice yield of 3.6% after the addition of 0.5% of water before whitening is of economic importance to rice millers, since rice milling is generally a low margin business. Further work is needed to overcome caking of moistened rice bran in the whitener. Hence, corrective measures to counteract caking will be the focus of follow-up work. Furthermore, biochemically assisted rice whitening needs to be proven for other rice varieties and different starting moisture contents. In addition, testing in an industrial setup is necessary in order to fully verify effectiveness. Finally, in-depth understanding of the increased whitening effect of sodium chloride and sorbit over water directly after whitening should be developed through additional analyses and the effect on cooking quality of rice should also be examined.

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Data availability

The data are not publicly available due to privacy restrictions.

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Conflict of interest disclosure

The authors declare no conflict of interest.

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Table 1 Summary of the tested rice whitening setups

	Reference 1	**Reference 2**	**Biochemically assisted rice whitening**
Pre-Whitening	None	1 lb / 5 s	None or 1 lb / 5 s
Liquid addition	None	None	0.5% or 1.0%
Type of liquid	None	None	water, Celluclast®, Viscozyme®, NaCl, sorbit
End Whitening	10 lbs / 15 s	10 lbs / 15 s	10 lbs / 15 s or 1lbs / 15s

Figure Legends

Fig. 1 Process flow sheet of conventional rice milling with relative yields of main- and co-products (Mueller-Fischer, 2012)

Fig 2 Broken kernels and whiteness of milled rice after one-step milling without moistening (Reference 1), two-step milling without moistening (Reference 2), biochemically assisted rice whitening with a moistening step in-between pre- and end-whitening using either 0.5 or 1.0% water, Viscozyme or Celluclast and end-whitening for 15 s at 10 lbs. Different letters indicate groups of significant differences

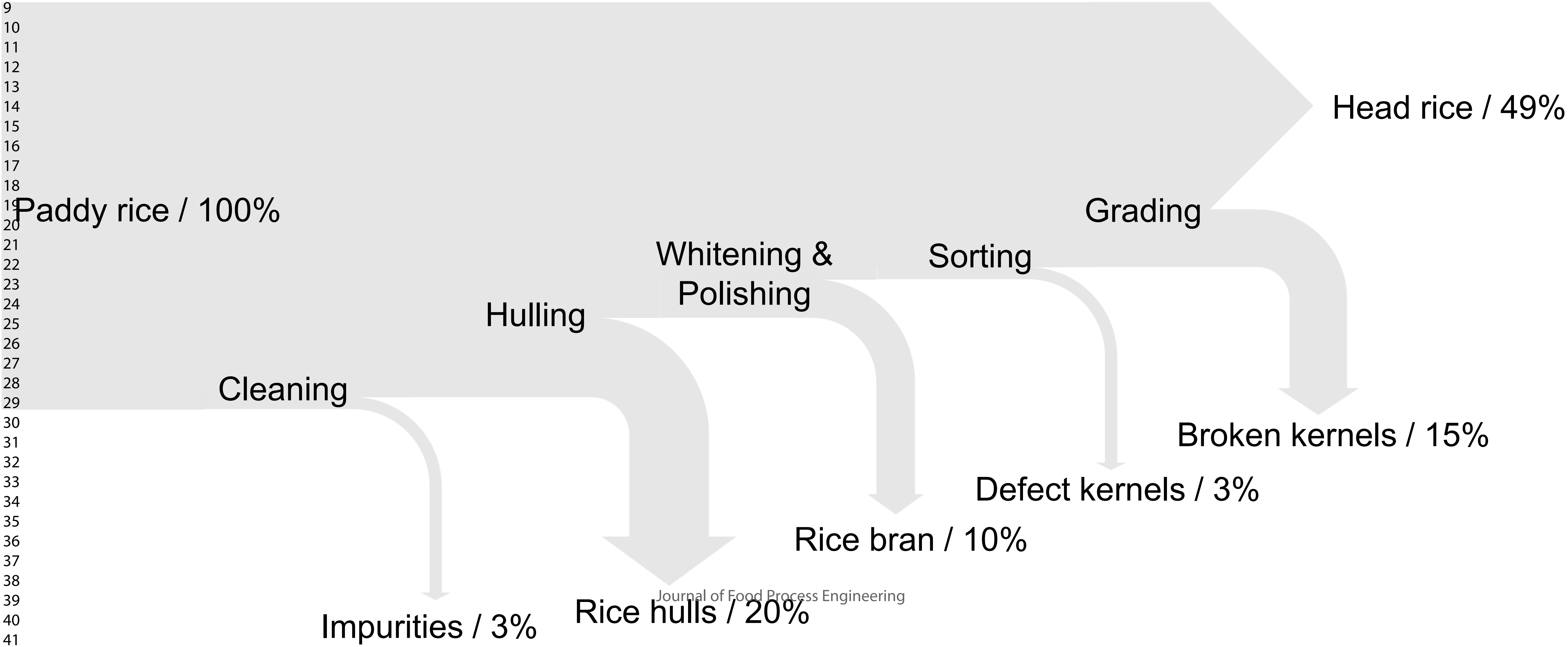
Fig. 3 Broken kernels and whiteness of milled rice after one-step milling without moistening (Reference 1), two-step milling without moistening (Reference 2), biochemically assisted rice whitening adding either 0.5% water, Viscozyme or Celluclast using different whitening processes (pre-whitening followed by whitening with 10 lbs for 15 s or 1 lbs for 15s, one-step whitening without pre-whitening and end-whitening performed at 1 lb for 15 s). Different letters indicate groups of significant difference

Fig. 4 SEM images of bran from USA parboiled rice (left), conventionally milled rice (middle) and rice milled using the biochemically assisted rice whitening process with water as moistening liquid (right)

Fig. 5 Comparison of reference milling and biochemically assisted rice whitening with different liquids (water, Viscozyme, Celluclast, sodium chloride, sorbit) at 0.5% concentration using a one step milling process and a milling weight of 1 lb for 15 s. Different letters indicate groups of significant difference

Supplementary Fig. 1 Moisture mass balance of reference 2. Moisture content determined by TGA (n = 3, except caking: n = 2).

Supplementary Fig. 2 Moisture mass balance for biochemically assisted rice whitening process setup with the addition of 1% addition water after pre-whitening at 1 lb for 5 s, a rest period of 1 minute and end whitening at 10 lbs for 15 s. Moisture contents determined by TGA (n = 3 for all fractions)


Paddy rice / 100%
Cleaning
Hulling
Whitening &
Polishing
Sorting
Grading
Head rice / 49%
Broken kernels / 15%
Defect kernels / 3%
Rice bran / 10%
Rice hulls / 20%
Impurities / 3%

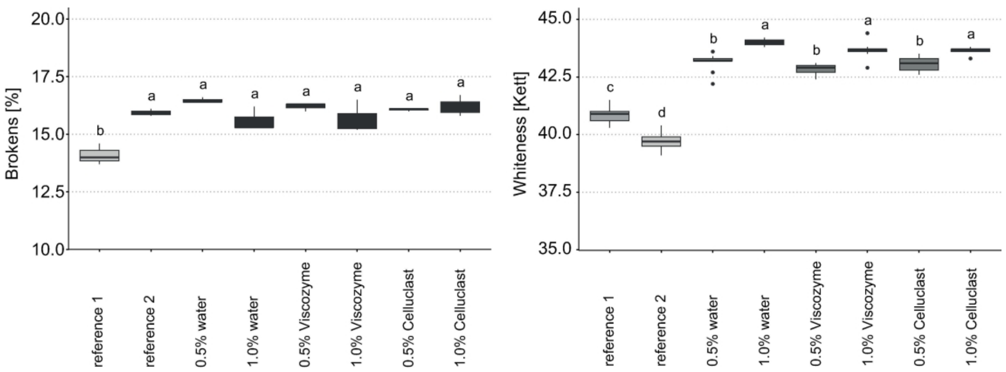


Fig 2 Broken kernels and whiteness of milled rice after one-step milling without moistening (Reference 1), two-step milling without moistening (Reference 2), biochemically assisted rice whitening with a moistening step in-between pre- and end-whitening using either 0.5 or 1.0% water, Viscozyme or Celluclast and end-whitening for 15 s at 10 lbs. Different letters indicate groups of significant differences

172x62mm (600 x 600 DPI)

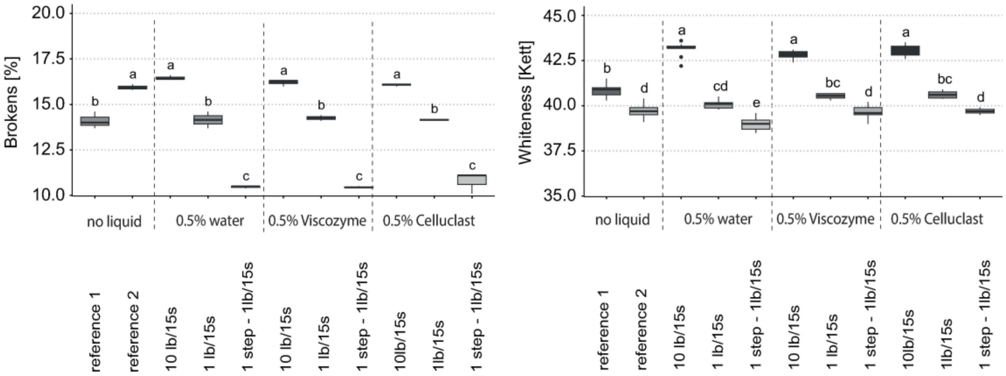
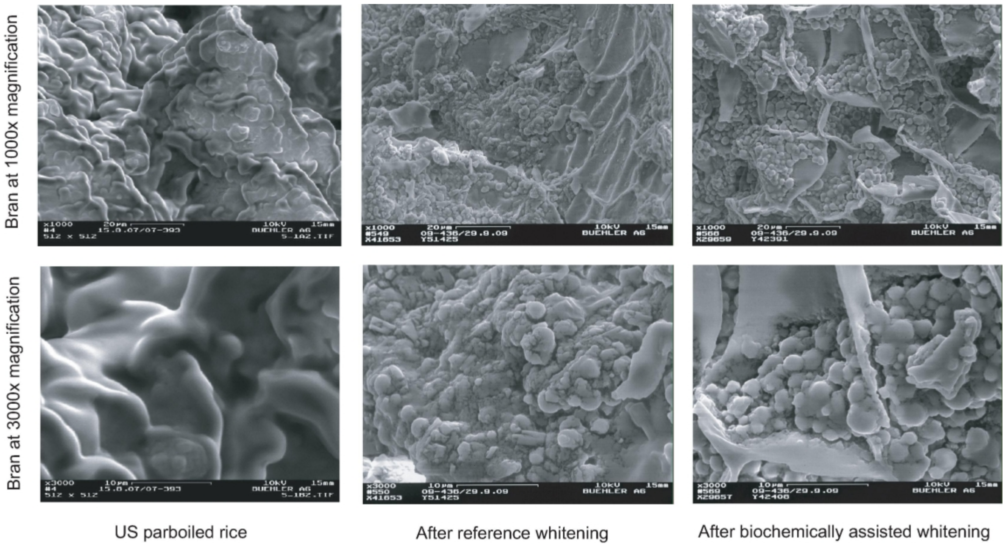


Fig. 3 Broken kernels and whiteness of milled rice after one-step milling without moistening (Reference 1), two-step milling without moistening (Reference 2), biochemically assisted rice whitening adding either 0.5% water, Viscozyme or Celluclast using different whitening processes (pre-whitening followed by whitening with 10 lbs for 15 s or 1 lbs for 15s, one-step whitening without pre-whitening and end-whitening performed at 1 lb for 15 s). Different letters indicate groups of significant difference

172x63mm (600 x 600 DPI)



US parboiled rice

After reference whitening

After biochemically assisted whitening

Fig. 4 SEM images of bran from USA parboiled rice (left), conventionally milled rice (middle) and rice milled using the biochemically assisted rice whitening process with water as moistening liquid (right)

142x77mm (600 x 600 DPI)

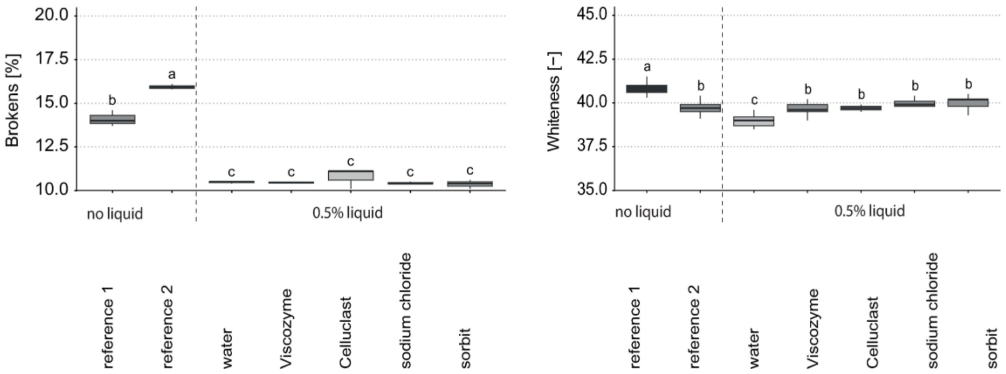


Fig. 5 Comparison of reference milling and biochemically assisted rice whitening with different liquids (water, Viscozyme, Celluclast, sodium chloride, sorbit) at 0.5% concentration using a one step milling process and a milling weight of 1 lb for 15 s. Different letters indicate groups of significant difference

167x61mm (600 x 600 DPI)