

Evaluation of Operating Conditions for Surface Lipid Extraction from Rice Using a Soxtec System

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ABSTRACT

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The degree of milling (DOM) of rice is a measure of how well the germ and bran layers are removed from the surface of rice kernels during milling. Because the majority of rice kernel lipids are found on the surface, measuring the surface lipid content (SLC) of rice after milling may be one way to quantify the DOM of rice. While there are several methods to measure the lipid content (LC) of rice, there is not an established standard method for determining the SLC of milled rice. The objective of this study was to evaluate the primary operating variables of a Soxtec apparatus in measuring the SLC of milled rice. This was accomplished by

varying the preextraction drying, boiling, rinsing, and postextraction drying durations, as well as the solvent used for extraction, to achieve the maximum extraction of lipids from rice. Experiments were performed on stored *Oryza sativa* L. 'Cypress' and 'Bengal' rice milled for 10, 30, and 60 sec. Results showed that durations of 1 hr of preextraction, 20 min of boiling, 30 min of rinsing, and 30 min of postextraction drying provided the maximum lipid extraction from milled head rice with petroleum ether. Of the three solvents tested, petroleum ether, and ethyl ether yielded similar extraction results.

Degree of milling (DOM) of rice refers to the extent to which the germ and bran layers of brown rice kernels are removed during the milling process. These bran layers include the pericarp, tegmen, nucellus, and aleurone (Shams-Ud-Din and Bhattacharya 1978). Thorough milling produces well-milled rice that has more bran removed and has higher starch content with lower lipid and protein levels than undermilled rice (Chen et al 1998; Perdon et al 2001). The amount of bran remaining on the kernel after milling affects the stability, quality, appearance, and end-use functionality of rice (Chen et al 1997).

Because bran is located on the surface of the rice kernel and is chiefly made up of lipids (15–20%) (Juliano 1985), the surface lipid content (SLC) of rice is directly related to how well the rice was milled, and thus gives an indication as to the DOM of the rice (Hogan and Deobald 1961; Pomeranz et al 1975; Miller et al 1979). Currently there are numerous methods used to measure the DOM of rice, including chemical, visual, and gravimetric measurements. The traditional methods of chemical analysis for lipid content (LC) in grain and animal feeds are the Soxhlet and Goldfish procedures (Methods 30-20 and 30-25, respectively, AACC International 2000). The USDA Grain Inspection, Packers and Stockyards Administration (GIPSA) also uses a Goldfish method for crude lipid determination of milled rice (USDA 1997). These procedures consist of drying the sample before extraction, percolating solvent through the sample, drying the extracted lipids in an oven, cooling the extracted lipid sample in a desiccator, and then weighing the lipid fraction collected in the extraction cup. The traditional Soxhlet and Goldfish procedures, however, are time-consuming, requiring up to 6 hr per extraction, with high solvent consumption. Also, traditionally, these procedures have been used to give an indication of the total or crude LC of ground rice. The Soxtec system has recently become more widely used for lipid extraction. While the Soxtec operation consists of basically the same extraction procedure as the Soxhlet or Goldfish procedures, the Soxtec system provides a faster, more automated, less solvent-consuming method for performing solvent extractions.

Several studies have compared the Soxtec system to existing lipid extraction procedures. Morrison (1990) compared the Soxtec

system with the official method Ac 3-44 (AOCS 1993) of Soxhlet lipid extraction in soybeans and found no significant difference ($P > 0.05$) between the two methods. The immersion or boiling duration, the duration the sample was rinsed with solvent, and the temperature of the hot plate were all critical factors in LC determination (Morrison 1990). Panozzo et al (1991) also compared the Soxtec method with the Soxhlet method for use in wheat, finding that the two instruments yielded similar results. Bhatti (1985) compared the Soxtec system with the Goldfish system (AOCS Method Ac 3-44) for crude lipid extraction using various oilseeds and grains. This study indicated that the Soxtec system gave lower lipid levels than the Goldfish system; although when samples were ground to pass through a 0.5-mm screen, the difference between the Goldfish and Soxtec systems was reduced (Bhatti 1985). These studies suggest that sample preparation and extraction system operation are important factors to consider when using either system.

There are four extraction system operations to consider when analyzing samples with the Soxtec system: preextraction drying, boiling, and rinsing of the rice sample, and postextraction drying of the extracted lipids. After the rice samples are weighed into the extraction thimbles, they are dried before extraction. This preextraction drying removes any residual surface moisture and facilitates lipid extraction (Pike 1994). During extraction, samples are immersed in boiling solvent for a certain duration and then lifted out of the solvent so that condensed solvent can drip through the sample, rinsing remaining lipids from the sample into the extraction cup (Fig. 1). After the boiling and rinsing operations, residual solvent is evaporated from the extracted lipid. While it is typically assumed, as will be done in this report, that the extracted lipids represent those lipids originally residing on the surface of kernels, there are questions as to whether some of the lipids were extracted from the internal portions of the kernel. As such, the procedure described above could conceivably yield LC values greater than the actual SLC. Currently, research is being conducted to determine the extent of Soxtec extraction penetration on lipid removal from milled rice.

Currently, there is no standard or officially accepted method for analyzing milled rice samples for SLC with the Soxtec system. As the use of the Soxtec system becomes more widespread, the importance of developing a standard method for its operation becomes more vital. The objective of this study was to evaluate the effects of Soxtec apparatus operating conditions by varying the preextraction drying, boiling, rinsing, and postextraction drying durations, as well as the solvent used for extraction, on the extraction of lipids from milled rice.

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MATERIALS AND METHODS

Sample Preparation

Cypress and Bengal rice, harvested in the Fall of 2001 from the Rice Research and Extension Center at Stuttgart, AR, at moisture contents (MC) of 19.2% (wb) and 16.7% (wb), respectively, were used for this experiment. The rough rice MC was determined by drying 15–20 g of rough rice in an oven at 130°C for 24 hr (Jindal and Siebenmorgen 1987). After harvest, the rice was cleaned with a dockage tester (model XT4, Carter Day Co., Minneapolis, MN). The rice was then stored at 7°C for approximately six months in sealed plastic buckets.

Before testing, the rice was dried on screen trays in a chamber (21°C, 53% rh) until the rice MC reached ≈12.5%. After drying, samples (150 g) of rough rice were dehulled using a laboratory huller (type THU, Satake, Tokyo, Japan), and the resultant brown rice was milled in a laboratory mill (McGill #2, RAPSCO, Brookshire, TX). During milling, a 1.5-kg weight was placed on the lever arm of the mill 15 cm from the centerline of the mill chamber. Samples were milled for 10, 30, or 60 sec to obtain samples with a wide SLC range. Head rice (milled kernels ≥75% of the original kernel length) was separated from broken kernels using a sizing device (Seedbuero Equipment Co., Chicago, IL).

Experimental Design

To determine the effect of extraction conditions on the lipid amounts removed from the rice, various durations of the four operations of a Soxtec extraction (preextraction drying, boiling, rinsing, and postextraction drying) were tested, as were three solvents (petroleum ether, ethyl ether, and hexane). Each Soxtec operation variable was tested separately, beginning with preextraction drying. While one variable was being tested, the variables that had not yet been established by this research were held constant at the durations suggested for fat extraction in both an application subnote (ASN 3132, Foss North America, Eden Prairie, MN) for extraction of (crude) fat in ground rice, and in previous methods used in this laboratory (Chen et al 1997).

Preextraction drying durations tested were 0, 1, 2, 4, or 24 hr. Boiling and rinsing durations tested were 0, 10, 20, 30, or 40 min. Postextraction drying durations of 0, 0.5, 1, 2, or 4 hr were evaluated (Table I). Each operation duration was tested three times with six samples comprising each extraction replicate for a total of 18 samples tested (three extractions × six samples per extraction) for both Bengal and Cypress rice for each of the milling durations (10, 30, and 60 sec).

Once an operation variable was tested, a Student's *t*-test was performed using JMP software (v. 5.0.1.2, SAS Institute, Cary, NC) to compare the mean values of the 18 samples tested for each treatment duration for both Bengal and Cypress. Based on the outcome of the statistical analysis testing for an operation, the experimental treatment level that resulted in the greatest SLC for that operation was held constant for subsequent testing of the other variables. If, however, the extraction data indicated that there was not a significant difference from other extraction dura-

tions, the shortest extraction duration was selected as the optimum. Also, the extraction duration that coincided with the results for the optimum extraction duration of the majority of the milling durations for both cultivars was selected if there was not a significant difference in the results.

Lipid Extraction

Surface lipid extraction was performed using a Soxtec system (Avanti 2055, Foss North America, Eden Prairie, MN). The Avanti 2055 has the capacity to perform extractions on six separate samples simultaneously. For analysis of SLC, 4–5 g of milled head rice was weighed into cellulose thimbles (33 mm, i.d. × 80 mm external length) (Foss North America). After recording the weight of the head rice, a defatted cotton plug (Foss North America) was placed on top of the sample to ensure that the sample remained immersed in the solvent, as well as to prevent the rice from boiling out of the extraction thimble.

To evaluate the effect of the preextraction drying duration, thimbles containing rice samples were predried in a convection oven maintained at 100°C. The oven temperature for both the pre- and postextraction drying durations was within the temperature range suggested by Foss for use with the Soxtec system of 102 ± 3°C (Soxtec Avanti 2055 instruction manual). Previous lipid extraction methods for the Soxhlet and Goldfish systems also recommended 100°C as the sample drying temperature. For these reasons, the pre- and postextraction drying temperatures were not varied. After preextraction drying, samples were placed in a desic-

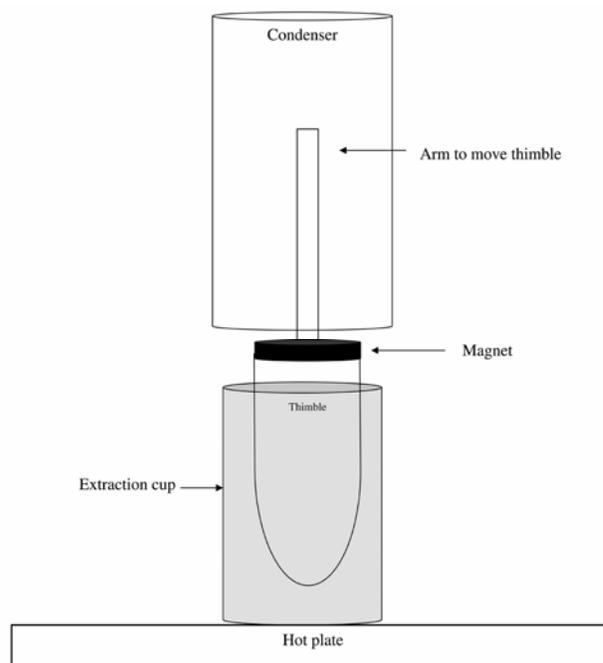


Fig. 1. Schematic and explanation of Soxtec system components.

TABLE I
Experimental Design for Evaluating the Four Operations of the Soxtec Avanti 2055 as well as the Solvent Used for Extraction^{a,b}

Operation	Operation Variables				Solvent
	Preextraction Drying	Boiling Duration	Rinsing Duration	Postextraction Drying	
Preextraction drying	0, 1, 2, 4, 24 hr	20 min	30 min	30 min	Petroleum ether
Boiling duration	1 hr	0, 10, 20, 30, 40 min	30 min	30 min	Petroleum ether
Rinsing duration	1 hr	20 min	0, 10, 20, 30, 40 min	30 min	Petroleum ether
Postextraction drying	1 hr	20 min	30 min	0, 0.5, 1, 2, 4 hr	Petroleum ether
Solvent	1 hr	20 min	30 min	30 min	Petroleum ether, ethyl ether, hexane

^a Each row represents the Soxtec operation or solvent being evaluated in a particular experiment and the variable durations and solvents used while testing each specific operation.

^b Eighteen extractions were performed for each experimental treatment combination.

cator to cool for ≈ 10 min. Meanwhile, three glass boiling beads (VWR International, Suwanee, GA) were added to the aluminum extraction cups to facilitate solvent boiling, and the weight of the extraction cups containing the beads was recorded.

After cooling in the desiccator, the thimbles containing the rice were attached to the magnets below the condensers in the Soxtec unit. When all six samples were in place, extraction cups were placed on the hot plate below the thimbles and 70 ± 5 mL of petroleum ether (boiling point $35\text{--}60^\circ\text{C}$) was measured into each extraction cup. When the extraction cups were secured into place and the hot plate below the extraction cups was heated to 135°C , the extraction cycle was started by immersing the thimbles into the solvent. This hot-plate temperature was the temperature recommended by Foss to achieve a condensed solvent flow rate of three to five drops/sec when using petroleum ether with aluminum extraction cups (Soxtec Avanti 2055 instruction manual).

After the specified boiling duration, the thimbles were raised out of the solvent and the rinsing operation was initiated. During rinsing, the evaporated solvent from the extraction cups condensed when contacting the condensers, which had cooling water ($\approx 20^\circ\text{C}$) running through them. The condensed solvent dripped down through the sample to rinse remaining lipids from the rice into the extraction cups. After rinsing, the lever on the Soxtec

system was moved into the solvent collection position to stop the solvent flow from the condensers back into the cups. The remaining solvent in the extraction cups was evaporated from the cups and collected in the solvent reservoir of the Soxtec system for later disposal.

When all of the solvent was evaporated from the extraction cups, as determined by visual examination, the cups containing the extracted lipids were removed from the Soxtec system and placed into an oven at 100°C . After the postextraction drying operation, the extraction cups containing the extracted lipids were placed in a desiccator to cool to room temperature for ≈ 30 min. The extraction cups were then removed from the desiccator and weighed. The difference in weight between the cups containing the extracted lipids and boiling beads and the original weight of the cups and beads was then calculated to obtain the weight of the extracted lipids. The SLC was calculated as the weight of extracted lipids expressed as a percentage of the weight of the original milled rice sample.

Solvent Variation

After operating conditions were established for each parameter with petroleum ether, the ethyl ether and hexane were also tested (Table I). The hot plate temperatures for ethyl ether and hexane

TABLE II
Mean Surface Lipid Contents (%) of Bengal and Cypress Rice Milled for 10, 30 or 60 sec Attained with Indicated Levels of Different Soxtec Operations^{a,b}

Operation	Milling Duration (sec)					
	Bengal			Cypress		
	10	30	60	10	30	60
Preextraction drying duration (hr)						
0	1.17bc	0.42c	0.25a	0.96b	0.41b	0.21a
1	1.23a	0.51a	0.25a	0.99a	0.43a	0.22a
2	1.21a	0.49ab	0.25a	0.94b	0.41b	0.16b
4	1.17c	0.48b	0.25a	0.91c	0.40b	0.17b
24	1.20ab	0.37d	0.16b	0.76d	0.39b	0.12c
Boiling duration (min)						
0	1.14b	0.40b	0.23b	1.0a	0.33bc	0.19b
10	1.21a	0.39c	0.24ab	0.96bc	0.32c	0.18b
20	1.24a	0.43a	0.25a	0.99ab	0.35a	0.22a
30	1.23a	0.37d	0.24ab	0.93c	0.32c	0.19b
40	1.22a	0.40bc	0.25a	0.98ab	0.34ab	0.19b
Rinsing duration (min)						
0	1.06c	0.41a	0.22c	0.86c	0.29bc	0.14c
10	1.17b	0.39b	0.22c	0.93ab	0.30ab	0.20ab
20	1.18b	0.37c	0.23bc	0.92b	0.31a	0.18b
30	1.23a	0.38bc	0.25ab	0.95ab	0.32a	0.22a
40	1.23a	0.37bc	0.26a	0.95a	0.28c	0.19b
Postextraction drying duration (hr)						
0	1.23a	0.56a	0.26a	0.95bc	0.43a	0.20b
0.5	1.23a	0.48c	0.20ab	0.98a	0.44a	0.22a
1	1.17b	0.52b	0.18b	0.97ab	0.42a	0.17c
2	1.17b	0.50c	0.22ab	0.93c	0.44a	0.19b
4	1.16b	0.49c	0.19ab	0.94bc	0.43a	0.18bc

^a Values are average of extractions from 18 samples. Durations of other operating variables used while testing a specific operating variable are shown in Table I.

^b Mean values in the same column with different letters represent operation durations that were significantly different.

TABLE III
Mean Surface Lipid Content (%) of Bengal and Cypress Rice Milled for 10, 30 or 60 sec and Extracted with Three Different Solvents in Soxtec Avanti 2055 Extraction System^{a,b}

Solvent	Milling Duration (sec)					
	Bengal			Cypress		
	10	30	60	10	30	60
Petroleum ether	1.23b	0.51a	0.25ab	0.99c	0.44a	0.22a
Ethyl ether	1.36a	0.51a	0.24b	1.18a	0.43a	0.20b
Hexane	1.26b	0.53a	0.27a	1.15b	0.40b	0.15c

^a Values are average of 18 samples. Extraction conditions: 1 hr of preextraction drying, 20 min of boiling, 30 min of rinsing, and 30 min of postextraction drying.

^b Mean values in the same column with different letters represent solvents that were significantly different.

were 135 and 165°C, respectively. These temperatures achieved a three to five drop/sec condensed solvent flow rate through the thimble on the Soxtec system (Soxtec Avanti 2055 instruction manual).

Comparison of Soxtec and Goldfish Methods

Samples of the same Bengal and Cypress rice used in the experiment above, milled for 10, 30 and 60 sec following the procedure outlined above, were also analyzed for SLC with a Goldfish extraction procedure for comparison with the Soxtec system. The Soxtec extractions were performed using the optimum operating durations established from the experiment described above (1 hr of preextraction drying duration, 20 min of boiling duration, 30 min of rinsing duration, and 30 min of postextraction drying duration) at the University of Arkansas, while Goldfish extractions were conducted by GIPSA personnel at Crowley, LA, using a USDA recommended method (USDA 1997). The Goldfish method consisted of extracting a 10-g sample of head rice in a Goldfish apparatus for 2.5 hr with petroleum ether, then evaporating the remaining ether and weighing the collected lipids. A Student's *t*-test was performed using JMP software (v. 5.0.1.2, SAS Institute, Cary, NC) to compare the mean values attained with each method for all rice lots.

RESULTS AND DISCUSSION

The preextraction drying duration providing the SLC that were greater than or equal to other durations for both Bengal and Cypress for each milling duration was 1 hr (Table II). The 20-min boiling duration provided the extraction result that was greater than or equal to the results from other extraction durations for both Bengal and Cypress rice milled for all durations. Both the 30-min rinsing and 30-min postextraction drying durations showed a slightly greater level of extracted lipids for Bengal and Cypress rice milled for most durations, except for Bengal milled for 30 sec. Bengal had the greatest extraction level with zero rinsing and zero postextraction drying durations. The reason for this finding is unknown and was not observed in the Cypress rice. Because the SLC of all other samples were greatest with a 30-min rinsing and 30-min postextraction drying duration, these durations were selected for further testing for both rinsing and postextraction drying.

Solvent Variation Results

For both Bengal and Cypress samples milled for 10 sec, which produces undermilled rice, ethyl ether extracted significantly greater SLC than petroleum ether or hexane (Table III). Extraction with petroleum ether resulted in extraction levels that were equal to or greater than the amount of lipids extracted with ethyl ether or hexane for Bengal and Cypress rice milled for 30 and 60 sec. Because ethyl ether provided the greatest level of lipid extraction for undermilled samples, as well as an extraction level equivalent to petroleum ether for all samples except for Cypress milled for 60 sec, it appears that ethyl ether is the most appropriate solvent for lipid determination of milled rice samples with a wide range of DOM.

There are other considerations to be made, however, when evaluating a solvent for extraction use. Not only is ethyl ether more expensive than petroleum ether, more explosive, and more hygroscopic, but it also forms peroxides more readily than petroleum ether (Min 1994). Because the extraction results were similar for both ethyl ether and petroleum ether, for most milled rice applications, lipid extractions using petroleum ether or ethyl ether should produce equivalent SLC values.

Comparison of Soxtec and Goldfish Methods

Surface lipid contents from the Goldfish extractions were significantly ($P < 0.05$) higher than those obtained from the Soxtec extractions (Fig. 2) for all of the Cypress head rice samples and

one of the Bengal head rice samples. Bhatti (1985) reported a similar finding when analyzing various grains and oilseeds with the Soxtec and Goldfish systems. Greater extraction results were obtained from the Goldfish analysis than from Soxtec analysis (Bhatti 1985).

Even though extraction results did not show significant differences for the Bengal samples milled for 30 and 60 sec, the average Goldfish SLC results were still greater than the average Soxtec SLC results (Fig. 2). The lack of significant differences between the Goldfish and Soxtec systems for Bengal milled for 30 and 60 sec may be due to the wider variation of results in the replicate samples for the Goldfish system (0.35–0.48 for rice milled 30 sec and 0.20–0.30 for rice milled 60 sec) compared with the Soxtec system (0.35–0.38 for rice milled 30 sec and 0.18–0.20 for rice milled 60 sec) for these two milling durations.

The differences between the Goldfish and Soxtec systems decreased as milling duration increased (Fig. 2). Because the Goldfish extraction is intended to measure the crude LC of ground rice, and the extraction duration is much longer than the Soxtec extraction, the Goldfish system may be extracting deeper into the layers of the rice kernels than the Soxtec system, particularly in undermilled rice. Further research is being conducted to establish the extent to which common extractions such as the Soxtec or Goldfish systems extract internal lipids, even when extractions are performed on whole kernels.

CONCLUSIONS

In evaluating the primary operating variables of a Soxtec extraction system for use in determining the SLC of milled rice, the extraction parameters providing the greatest SLC values were 1 hr of preextraction drying, 20 min of boiling, 30 min of rinsing, and 30 min of postextraction drying. Extractions using both petroleum ether and ethyl ether yielded similar results except in undermilled rice, in which ethyl ether yielded greater SLC than petroleum ether. With safety and other concerns considered, petroleum ether may be the best solvent for measuring the SLC of milled rice.

When comparing the Goldfish extraction results with the Soxtec extraction results, the Goldfish system yielded greater SLC values than the Soxtec system. This may be due to the extraction of lipids from a greater depth in the kernel by the Goldfish system than by the Soxtec system, especially from undermilled rice. Further studies are underway to determine the extent of solvent penetration on lipid removal from milled rice.

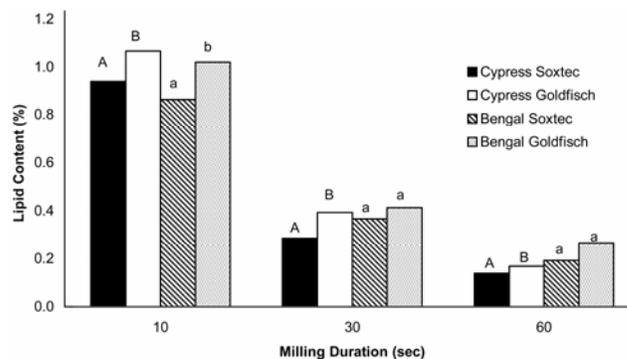


Fig. 2. Comparison of three different milling durations (10, 30, and 60 sec) for Cypress and Bengal rice extracted with both the Soxtec and Goldfish extraction systems. Each data point is the average of three samples. Statistical differences ($P = 0.05$) are indicated with letters above each bar. Capital letters indicate statistical differences between Cypress samples analyzed with the Soxtec and Goldfish systems, while lower case letters indicate differences between Bengal samples.

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