Carbohydrate Polymers 146 (2016) 253–263

Contents lists available at ScienceDirect

Carbohydrate Polymers

journal homepage: www.elsevier.com/locate/carbpol

Instrumental measurement of cooked rice texture by dynamic rheological testing and its relation to the fine structure of rice starch

Hongyan Li[a], Sangeeta Prakash[b], Timothy M. Nicholson[c], Melissa A. Fitzgerald[b], Robert G. Gilbert[a,*]

[a] The University of Queensland, Centre for Nutrition and Food Sciences, Queensland Alliance for Agriculture and Food Innovation, Brisbane 4072, QLD, Australia
[b] The University of Queensland, School of Agriculture and Food Science, Brisbane 4072, QLD, Australia
[c] The University of Queensland, School of Chemical Engineering, Brisbane 4072, QLD, Australia

ARTICLE INFO

Article history:
Received 24 December 2015
Received in revised form 8 March 2016
Accepted 17 March 2016
Available online 19 March 2016

Keywords:
Rice
Rheology
Texture
Molecular structure

ABSTRACT

Increasing demands for better instrumental methods to evaluate cooked rice texture is driving innovations in rice texture research. This study characterized cooked rice texture by descriptive sensory analysis and two instrumental methods (texture profile analysis (TPA) and dynamic rheological testing) using a set of 18 varieties of rice with a wide range in amylose content (0–30%). The panellists' results indicated that hardness and stickiness were the two most discriminating attributes among 13 tested textural attributes. The consistency coefficient (K^*) and loss tangent (tan δ) from a dynamic frequency sweep were used to compare with hardness and stickiness tested by TPA and sensory panellists, showing that using K^* to express hardness, and tan δ to express stickiness, are both statistically and mechanistically meaningful. The instrumental method is rationalized in terms of starch structural differences between rices: a higher proportion of both amylose and long amylopectin branches with DP 70–100 causes a more elastic and less viscous texture, which is readily understood in terms of polymer dynamics in solution.

1. Introduction

Rice is a major staple food world-wide. In recent years, consumer preferences have shifted towards better-quality rice, particularly towards varieties with good eating quality. Each country, and often region, prefers rice with a particular suite of quality traits. The textural attributes of cooked milled rice are of prime importance to its eating quality (Calingacion et al., 2014). Descriptive sensory analysis is an objective tool used to characterize textural traits of foods (Meilgaard, Carr, & Civille, 2006). The technique has been used extensively for determining the effect of different growing and/or processing conditions on sensory properties of rice (Champagne et al., 2010; Lyon, Champagne, Vinyard, & Windham, 2000; Lyon et al., 1999; Meullenet, Gross, Marks, & Daniels, 1998). However, the cost associated with training and maintaining a sensory panel has prompted many researchers to evaluate less costly and less time-consuming instrumental approaches.

Most rice is consumed in the form of grains, rather than after processing to flour, which raises challenges in collecting rheological data that are relevant to the sensory experience of eating rice. As such, texture analysers, where individual grains are placed on a plate, are currently the most commonly used instruments to measure the texture of cooked rice kernels (Ayabe, Kasai, Ohishi, & Hatae, 2009; Billiris, Siebenmorgen, Meullenet, & Mauromoustakos, 2012; Cameron & Wang, 2005). This method has been employed with some success and, in some cases, provides data that relate closely to sensory evaluation data (Prakash et al., 2005; Sesmat & Meullenet, 2001). However, its limitations restrain some applications. The texture analyser is used to obtain the force-displacement curve by a double-compression test of typically two rice kernels, which is less reliable and accurate than a test performed on bulk samples (Juliano et al., 1984). The poor repeatability of this method has been reported when conducted on freshly cooked rice, due to the rapid retrogradation of rice starch with decreasing rice temperature, which, consequently, results in more replicates and complex sample preparation needed to obtain statistically meaningful data (Meullenet et al., 1998). Furthermore, the range of geometries available for texture analysers has also meant that standard fixtures and procedures are not always used,

* Corresponding author.
E-mail address: b.gilbert@uq.edu.au (R.G. Gilbert).

http://dx.doi.org/10.1016/j.carbpol.2016.03.045
0144-8617/

which makes it difficult to compare studies. While not always practiced, measurements should always be reported as stress rather than force to allow comparisons to be made between geometries and methodologies (Stokes, Boehm, & Baier, 2013). The texture-profile analyser (TPA) mimics the first bite of a food sample (Stokes et al., 2013), corresponding to Phase II in Table S1. There has been extensive work using rheometers to measure properties of food materials in relation to food microstructure and sensory texture (Chen & Stokes, 2012; Foegeding et al., 2011). Compared to conventional TPA measurements, rheological studies have the benefits of a well-defined geometry and deformation process, related to fundamental mechanical parameters (such as stress, strain, strain rate, storage and loss moduli, etc.) for quantitative descriptions of food materials. However, while rheological properties have been extensively investigated to relate to the texture/mouthfeel of liquid and semi-fluid foods, there are unanswered questions relating to their use for semi-solid or solid foods (Foegeding et al., 2011), e.g. cooked white rice.

Starch is the major component of rice grains, and starch structure is considered to be the most important factor affecting the cooking quality of rice, e.g. gelatinization temperature (Cuevas et al., 2010), starch swelling (Hasjim, Li, & Dhital, 2012), starch leaching (Patindol, Gu, & Wang, 2010), which determine the texture of cooked rice. Amylose content has since the mid-1980s been considered to be the most important determinant of the eating quality of rice (Bhattacharya & Juliano, 1985). In the mid-1990s, it was proposed that the texture of cooked rice is also related to the fine structure of amylopectin (Reddy, Ali, & Bhattacharya, 1993). In previous work, we found that the fine structure of amylose, both molecular size and chain-length distribution, are also significant determinants of the hardness of cooked rice (Li, Prakash, Nicholson, Fitzgerald, & Gilbert, 2016).

In this study, properties of a diverse set of rices with a wide range of amylose contents were evaluated by a trained panel and two instruments. A novel instrumental method, dynamic rheology with vane geometry, was developed to compare with the conventional TPA method and with textural perceptions of a sensory panel. The fine structure of amylopectin and amylose was measured to identify the structural origins of the textural differences between rice samples.

2. Materials and methods

2.1. Materials

18 milled rice grain samples were chosen from a collection of rice varieties with known phenotypes and genotypes for quality traits (Table 1). After harvesting, all rice samples were dehulled in a dehusker (Otake, Aichi, Japan), polished to yield rice with the same whiteness value in a commercial mill (FASCO, VIC, Australia), and then stored in self-sealing plastic bags in a refrigerator before subsequent analyses.

Protease from *Streptomyces griseus* (type XIV), and LiBr (ReagentPlus) were purchased from Sigma-Aldrich Pty. Ltd. (Castle Hill, Australia). Isoamylase (from *Pseudomonas* sp.) and a D-glucose (glucose oxidase/peroxidase; GODOP) assay kit were purchased from Megazyme International, Ltd. (Wicklow, Ireland). 8-Aminopyrene-1,3,6,-trisulfonate (APTS), included in the Carbohydrate Labelling and Analysis Kit, was purchased from Beckman Coulter (Brea, USA). A series of pullulan standards with peak molecular weights ranging from 342 to 2.35×10^6 were from Polymer Standards Service (PSS) GmbH (Mainz, Germany). Dimethyl sulfoxide (DMSO, GR grade for analysis) was from Merck Co. Inc. (Kilsyth, Australia). All other chemicals were reagent-grade and used as received.

2.2. Rice cooking

Rice (600 g, 14% moisture content) was rinsed with distilled water three times. As shown in Table 1, distilled water was added to the rice to give rice-to-water weight ratios for three different cooking types based on amylose content (1:1.3, 0%; 1:1.6, 10–25%; 1:1.8, 25–30%). The high ratio for high-amylose rices is often used; such rices do not become sticky after cooking even with this high ratio. The cooking process was conducted using the pre-set cooking setting of a rice cooker (Kambrook Rice Express, VIC, Australia), followed by a 10 min holding period at the warming setting. The top 1 cm layer of cooked rice and rice adhering to the sides of rice cooker were not used. Cooked rice for sampling was taken directly from the middle of each cooker, transferred to a pre-warmed (120 °C) glass bowl, and mixed thoroughly while minimizing kernel breakage. The glass bowl was then kept in a 50 °C water bath for sensory evaluation.

2.3. Sensory evaluation protocol

10 panellists trained in the principles and concepts of descriptive sensory analysis (Meilgaard et al., 2006) participated in the study. The sensory lexicon included 13 sensory attributes that described rice texture at different phases of eating, beginning with the feel of the rice when it is first placed in the mouth and ending with mouthfeel characteristics after the rice swallowed (Table S1 in the supplementary data). Each sample was presented to the panellists twice, following a randomized design in which each session consisted of four samples, a standard, and a blind control (Sunrice® long grain, a commercial cultivar). The standard, which was the warm-up sample presented at the beginning of each session, was used to calibrate the panel. After the warm-up sample, coded test samples were presented to panellists individually at 20 min intervals immediately after cooking, holding, and portioning into serving cups. Evaluations were conducted at individual test stations. Spring water was used to cleanse the mouth between samples.

2.4. TPA

A 1 g subsample of cooked rice grains was weighed and placed as a single layer of grains on a flat glass dish. Then TPA measurements were conducted using the method described previously (Li et al., 2016).

2.5. Dynamic viscoelasticity measurement

Dynamic viscoelasticity measurements were carried out in a stress-controlled rheometer AR G2 (TA instruments, USA) with a controlled temperature Peltier element set at 37 °C. The geometry used was specially designed for small sample volumes. A four-bladed vane geometry with a diameter of 15 mm and a length of 15 mm, and a cup with a diameter of 40 mm were used (TA instruments, USA). After cooking, 25 g of cooked rice grains were immediately loaded into the cup and gently packed to remove air. The vane was then set down to a distance of 4 mm from the bottom of the cup and was completely immersed in the rice bulk. No mineral oil was added to the top of the cooked rice kernels to avoid mixing with the food bolus. After the vane temperature decreased to 37 °C, the rice bolus was allowed to rest for 5 min before the following tests were implemented.

Two dynamic tests were performed: (a) An oscillatory stress sweep test from 0.1 to 1000 Pa, at a constant frequency of 10 rad/s and 37 °C, was made to set the upper limit of the linear viscoelastic region (LVR). (b) A frequency sweep over a range of 0.1–100 rad/s at 37 °C was performed at the oscillatory stress of 2 Pa, which is