Developing final product specifications for long-grain parboiled rice (*Oryza sativa L.)* based on South African consumer preference

By

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DECLARATION

By submitting this dissertation electronically, I declare that the entirety of the work contained therein is my own, original work, that I am the sole author thereof (save to the extent explicitly otherwise stated), that reproduction and publication thereof by Stellenbosch University will not infringe any third party rights and that I have not previously in its entirety or in part submitted it for obtaining any qualification.

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ABSTRACT

The objective of this study was to determine the sensory and physicochemical characteristics of long grain parboiled rice that drive consumer liking, in order to generate a product specification that could ultimately be used for setting up a protocol, of processing parameters for long grain parboiled rice.

A trained panel applied descriptive sensory analysis (DSA) to characterise the sensory attributes of 12 imported, commercially produced long grain, parboiled, rice samples. The rice samples were differentiated in both its raw and cooked format, by characterising its appearance, aroma, flavour and textural attributes. A consumer panel, comprising of 75 target consumers, rated preference for eight of the parboiled rice samples, in both its raw and cooked format, on a 9-point hedonic scale. Consumers, screened for the task, represented the key rice consuming ethnic groups from three major provinces within South Africa. In-depth consumer opinions and attitudes towards long grain parboiled rice were also examined, using the focus group technique. Physicochemical analysis were performed on all the rice samples, including colour measurement of both raw and cooked rice samples; firmness and stickiness measurement, viscosity measurement, degree of gelatinisation and the protein and amylose content of the samples.

Analysis of variance (ANOVA) was conducted on the sensory and physicochemical data, as well as the consumer liking data. Multivariate analyses were performed on the sensory and consumer data, to determine whether relationships existed between the sensory and physicochemical sample attributes and consumer liking. Partial least squares regression (PLS) was performed, in an attempt to relate consumer degree of liking data, and the sensory and physicochemical data.

The preferred raw rice samples were characterised mainly by the primary attribute of appearance, as having high whiteness intensity. The preferred cooked rice samples were mainly characterised by the primary attributes of appearance, (high whiteness intensity and swollen/plump appearance), and texture (slight stickiness in mouth, starchy mouthfeel after 5 chews and slight grain-to-grain stickiness). Sensory attributes of high firmness and springy/rubbery, and oily aroma mainly characterised the cooked samples that were not preferred. From a sensory perspective, the whiteness intensity, therefore, drives raw rice liking, whereas cooked rice liking is driven by a high degree of swollen/plump appearance, high whiteness intensity, and a relative amount of stickiness in mouth, starchy mouthfeel after 5 chews and grain-to-grain stickiness. Results show that consumers are not similar in their sensory requirements; attitudes and behaviour towards long grain parboiled rice therefore, differ. The physicochemical drivers, associated with both the raw and cooked preferred rice samples, were colour, degree of gelatinisation and viscosity properties.

Based on the consumer preference for specific sensory characteristics of long grain parboiled rice, together with analytical measurements, consumer sensory demands can be translated into final product specifications. These specifications, in turn, can then be used as a first step toward setting up processing parameters, to ultimately achieve the desired quality of long grain parboiled rice.

OPSOMMING

Die doel van hierdie studie was om te bepaal watter spesifieke sensoriese en fisies-chemiese eienskappe die verbruikersaanvaarbaarheid van gedeeltelik gekookte langgraan rys dryf. Hierdie eienskappe is daarna gebruik om finale produkspesifikasies te genereer wat as basis kan dien vir die opstel van ‘n prosesseringsprotokol wat daarop gemik is om die produkaanvaarbaarheid, soos aangedui deur die verbruiker, te verseker.

Beskrywende sensoriese analise en ‘n opgeleide paneel is gebruik om die sensoriese eienskappe van 12 ingevoerde, kommersieel-vervaardigde, gedeeltelik gekookte langgraan rys vas te stel. Beide die rou en gaar rys monsters is ten op sigte van hul voorkoms, aroma, geur en tekstuur beskryf. ‘n Verbruikerspaneel, wat uit 75 individue bestaan het, se voorkeur en aanvaarbaarheid vir agt gedeeltelik gekookte langgraan rys monsters, beide rou en gaar formaat, is bepaal deur van die 9-punt hedoniese skaal gebruik te maak. Die geselekteerde verbruikerspaneel was verteenwoordigend van die algemene rysverbruiker, asook drie etniese groepe in drie sleutel provinsies in Suid-Afrika. Die fokusgroeptegniek is ook gebruik om in-diepte inligting te verkry rondom verbruikeropinies en –houdings ten opsigte van gedeeltelik gekookte langgraan rys. Fisies-chemiese analises is uitgevoer op al die rys monsters, en dit het instrumentele kleurbepalings van beide die rou en gaar rys monsters ingesluit, sowel as die meting van die fermheid en klewerigheid van die rys. Die viskositeit, die mate van gelatinisering, asook die amilose en proteïeninhoud van die rys monsters is ook bepaal.

Analise van variansie (ANOVA) is op sensoriese, fisies-chemiese en verbruikersdata toegepas. Meerveranderlike analise is uitgevoer op die sensoriese en verbruikersdata ten einde te bepaal of spesifieke sensoriese produkeienskappe verbruikersvoorkeur dryf. Meervoudige regressie analise is toegepas om die verwantskap tussen verbruikersvoorkeur, sensoriese en fisies-chemiese produkeienskappe te bepaal.

Volgens die verbruikersresultate moet die rou formaat van langgraan rys verkieslik ‘n kenmerkende wit kleur hê. Die primêre voorkoms eienskappe van goeie kwaliteit gaar langgraan rys sluit in ‘n tipiese wit kleur en ‘n ‘n uitgeswelde voorkoms. Die primêre teksturele eieskappe is beskryf deur ‘n effense klewerig, styselagtige mondgevoel en ‘n effense ryskorrel klewerigheid. Die sensoriese eienskappe van die rys wat nie deur die verbruiker verkies is nie, sluit rys in met ‘n hoë fermheid en rubberagtig mondgevoel. Vanuit ‘n sensoriese perspektief word verbruikersvoorkeur van rou rys dus primêr gedryf deur ‘n wit kleur, terwyl die aanvaarbaarheid van gaar rys meestal gedryf word deur ’n wit en uitgeswelde voorkoms, ‘n effense klewerig, styselagtige mondgevoel, asook ‘n effense ryskorrel klewerigheid. Die resultate dui egter ook aan dat verbruikers nie in ooreenstemming is in hul sensoriese behoeftes, opinies of houdings jeens gedeeltelik gekookte

langkorrel rys nie. Die fisies-chemiese eienskappe wat verbruikersaanvaarbaarheid van hierdie variant rys, in beide die rou en gaar formaat, dryf sluit mate van gelatinisering en viskositeit in.

Die spesifieke sensoriese en fisies-chemiese eienskappe van goeie kwaliteit gedeeltelik gekookte langkorrel rys wat geassosieer is met verbruikersaanvaarbaarheid, is in hierdie studie omskep in ‘n stel kwalitietvereistes, saamgevat in produkspesifikasies. Hierdie spesifikasies is die eerste stap tot die daarstelling van prosesseringsprotokol ten einde gedeeltelik gekookte langkorrel rys van optimum kwaliteit te produseer.

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This thesis is presented in the format prescribed by the Department of Food Science at Stellenbosch University. The structure is in the form of one or more research chapters (papers prepared for publication) and is prefaced by an introduction chapter with the study objectives, followed by a literature review chapter and culminating with a chapter for elaborating a general discussion and conclusion. The language, style and referencing format used are in accordance with the requirements of the *International Journal of Food Science and Technology*. This thesis represents a compilation of manuscripts where each chapter is an individual entity and some repetition between chapters has, therefore, been unavoidable.

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CHAPTER 1

INTRODUCTION

The consumption of rice (*Oryza sativa L.*) is on the increase, not only in countries where it is primarily produced, but also in Southern Africa. Rice imported into South Africa is expected to increase to approximately 1 million tons in 2014. This is a rise of about 8%, from an estimated 925 000 tons in the previous year. This increase over the last few years can be attributed to the high price of rice-substituting crops, such as maize and wheat. Since South Africa depends entirely on rice imports to meet its domestic demand, the rice market is becoming more and more competitive, as many new importers and packers emerge. Thailand, India, Brazil and Vietnam are the major exporters of rice to South Africa (Anon., 2013). The bulk of the imported rice is made up of parboiled rice.

Parboiled rice is produced by soaking, steaming, drying and milling of paddy rice, i.e. rice of which the husk or hull has not yet been removed. This hydrothermal process changes the crystalline structure of rice starch to an amorphous structure, by irreversible swelling and fusion of the rice starch; however, it does not affect the size or the shape of the rice kernel (Bor, 1991). Globally, only about a fifth of the world's rice is parboiled (Bhattacharya, 2004). The rest is used in the raw milled format. The initial reason for parboiling was to reduce breakages during milling, thereby increasing the milling yield. Later on it was found that parboiled rice is nutritionally superior to raw (non-parboiled rice), especially when comparing the vitamin B content of parboiled and non-parboiled rice(Bhattacharya, 2004) .

The parboiling process brings about fundamental physical changes in rice that can be detected sensorially. The colour of rice changes from opaque and white to glassy, translucent and amber. Parboiled rice is usually slightly shorter, but broader than raw (non-parboiled) rice. Cooked parboiled rice is firmer, fluffier and less sticky than non-parboiled rice. The cooking time of parboiled rice is also increased by the parboiling process (Bhattacharya, 2011). The degree to which these changes occur depends on numerous factors, but the type of parboiling and the intensity of the parboiling process plays a critical role (Kimura *et al.*, 1976, 1983; Bhattacharya & Ali 1985; Bhattacharya, 1996; Lu & Lii, 1996).

Starch is the major constituent of rice and accounts for more than 80% of the total components present. Amylose, in turn, is the major compound influencing the physicochemical properties of rice starch (Vandeputte & Delcour, 2004).

Until very recently, South Africa had no regulations relating to rice specifications or rice quality. The new regulations, although still in draft format, are more focused on the grading and packaging of rice and little mention is made of the sensory quality of the rice. The current draft only states that a consignment of rice shall be free from abnormal flavours and odours, but these flavours and odours are not defined or described (Anon., 2014).

South African long-grain parboiled rice consumers can be classified as belonging to either the premium or the non-premium purchasing category. The consumer interested in purchasing in the non-premium category can be regarded as being very price sensitive; this consumer does not really care much about consistently good quality and for this consumer, quality should just be acceptable with each purchase. In contrast, the premium rice consumer is not very price sensitive but is willing to pay more, and for this consumer the rice must be of a high, consistent quality. In order to retain and gain market share, the South African consumers' preference for premium long-grain parboiled rice has to be determined. Studies on consumer acceptability of parboiled rice, however, remain limited (Demont *et al*., 2012).

Descriptive sensory analysis (DSA) is an objective tool that can be used to effectively characterise and analytically measure traits of aroma, flavour and texture of foods by a trained panel (Meilgaard *et al.*, 2007). The technique has been used extensively for determining the effect of different processing conditions on the sensory attributes of rice (Champagne *et al.*, 1997, 2004a, 2004b, 2007, 2009; Meullenet *et al.,* 1999, 2000). Rice importers should not only be familiar with the attributes that drive consumer preference in South African, but also whether these drivers differ for consumers belonging to the respective rice quality groupings.

Preference mapping is a sophisticated multivariate data-analysis technique that has been widely used, to relate consumer preferences to product characteristics and to understand the key sensory attributes that drive consumer preference (Lawless & Heymann, 2010). Internal preference mapping visualises the consumer preference with the products that were evaluated in a single data set. External preference mapping visualises two data sets simultaneously, i.e. consumer preference and sensory attribute ratings (generated by descriptive sensory analysis) or instrumental data, collected for the same products (Faber *et al*., 2003).

The sorting task has been developed as a rapid method of profiling food products as an alternative to DSA. Various papers have compared the sorting task with conventional sensory profiling (Tang & Heymann, 1999; Saint–Eve *et al*., 2004; Soufflet *et al*., 2004; Faye *et al*., 2004, 2006; Cartier *et al*., 2006; Blancher *et al*., 2007; Lelièvre *et al*., 2008, 2009). The sorting task is a simple method for collecting similarity data (Healy & Miller, 1970; Coxon, 1999) and could be used with success in industry.

The aim of this study was to identify, firstly, the sensory characteristics that drive consumer acceptance of long-grain parboiled rice, and secondly, the instrumental drivers of sensory quality. Specific chapters included:

- A comprehensive literature review will be presented in Chapter 2. Rice as the substrate for producing parboiled rice will be discussed and conceptualised. Reference will be made to the consumption and composition of rice. The physical properties of rice will be outlined and the processing of rice summarised. Parboiled rice processing and properties will be discussed and reference will be made to history and consumption patterns. Finally, quality grading of parboiled rice will be outlined and some parboiled rice eating qualities will be discussed.

- Chapter 3 will examine the results of DSA conducted on the 12 long-grain parboiled rice samples. The rice samples, both raw and cooked, will be characterised and differentiated by appearance, aroma, flavour and textural attributes. Analysing the sensory characteristics of a broad range of long-grain parboiled rice samples will generate a sensory profile for the product category of long-grain parboiled rice. The profile will make it possible to establish a sensory lexicon for long-grain parboiled rice, which will include a list of sensory attributes, definitions and reference samples that could be used in industry, as a valuable quality control tool.
- Chapter 4 will determine to what degree the rapid sorting technique can be used to replace DSA, for the sensory profiling of premium long-grain parboiled rice.
- Chapter 5 details the results of the consumer preference for 12 premium long-grain parboiled rice samples, using hedonic tests. The sensory drivers of consumer preference will also be determined, using advanced regression analyses techniques. Partial least squares regression will be used to establish a greater understanding of the descriptive sensory attributes, that influence consumer preference and examine the relationship between descriptive sensory analysis and consumer liking of long-grain parboiled rice. The focus group technique will be utilised, after completion of the hedonic testing to determine whether there is trade-off between the various general quality drivers as perceived by these consumers.
- Chapter 6 will discuss the various analyses conducted on the 12 premium long-grain parboiled rice samples being investigated in this study. These analyses include amylose content, differential scanning calorimetry (DSC), rapid viscosity analysis (RVA), protein content, colour of both raw and cooked rice samples, texture(firmness and stickiness), and general grading analysis. The analytical drivers of sensory attributes will also be determined, using advanced regression analysis techniques. Partial least squares analysis will be used to establish a greater understanding of the analytical properties that influence sensory quality and examine the relationship between analytical properties and sensory attributes for long-grain parboiled rice.
- Chapter 7 will provide a general discussion and conclusions regarding the research findings. Preliminary sensory and physicochemical quality specifications will be defined, which can be used as the basis for setting up a future processing parameter protocol. Processing parameter recommendations will further be deliberated upon.

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CHAPTER 2

LITERATURE REVIEW

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1. Introduction

Rice (*Oryza sativa L.*) is a key staple food for almost half of the world's population, providing 21% of the worldwide human per capita energy and 15% per capita protein. Rice can be consumed in many different forms, which include whole grains (brown, milled or parboiled), flour and fermented products (Oli *et al*., 2014). South Africa does not cultivate any rice domestically and subsequently, is a net importer of rice. The imports include brown, milled and parboiled rice, but out of all these rice formats, predominantly parboiled rice is imported into South Africa. Parboiled rice is produced by a process of soaking, cooking and drying of paddy before milling (Fig.1).

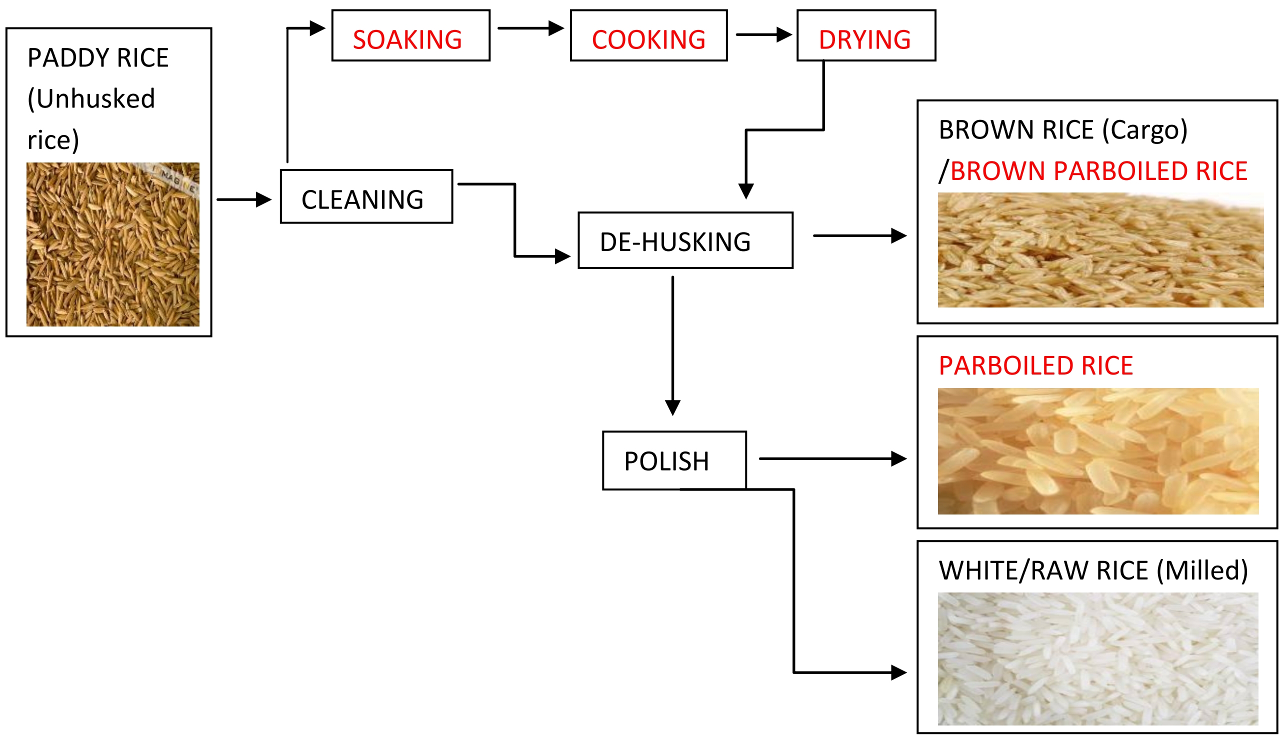

Fig. 1 Rice processing of milled, brown and parboiled rice.

The purpose of this literature review is fourfold. Firstly, rice, as the substrate for parboiled rice production, will be discussed to gain insight into rice composition, properties and processing. Parboiled rice, as the most consumed format of rice in South Africa, will be explored; and secondly, the processing and properties, associated with parboiled rice, will be reviewed. Following this, the quality grading of parboiled rice will be reviewed, and lastly, the eating quality of parboiled rice will be discussed, specifically to gain an insight into the physicochemical properties, cooking tests and cooked rice properties, associated with parboiled rice.

2. Rice

2.1 Introduction

Rice is a monocotyledonus angiosperm, belonging to the genus *Oryza*. Within this genus there are 20 species, of which only two are referred to as cultivated rice: *Oryza sativa*, which is cultivated in South East Asia and Japan, and *Oryza glabberrrima*, which is cultivated in West Africa (Watanabe, 1997). There are two main varieties of *Oryza sativa*, namely Indica and Japonica. Indica rice grains can be either small or long; generally, grains are slender and have a rather high amount of amylose. The cooked rice tends to have a firm and non-sticky texture and is mainly cultivated in South and South-East Asia. Japonica rice can be defined as having short and round grains, a low amylose content, and upon cooking, tend to be soft and sticky in texture; it is mainly cultivated in East and North-East Asia (Bhattacharya *et al*., 1980).

Cultivated rice (*Oryza sativa L.)* is one of the leading food crops of the world – the staple food of over half the world's population (Juliano, 1972). Approximately 90% or more of the world's rice is produced in a relatively small area, collectively referred to as "the rice countries of Asia" (Fig. 2). This area is made up of South, South-East and North-East Asia (Bhattacharya, 2011).

Fig. 2 The rice-producing countries of Asia (maps.com).

2.2 Rice consumption

Rice is grown in more than a 100 countries on every continent, except Antarctica (Champagne *et al*., 2004). Rice is the staple food of East, South-East and South Asia, with this region as a whole accounting for more than 90% of global production and consuming more than 88% of production (Luh, 1991).

The bulk of rice consumed globally is in its fully milled form, either raw or parboiled; brown rice accounts for a much smaller share. Rice can also be consumed in different forms such as noodles, puffed rice, fermented sweet rice, and many snack foods and breakfast cereals made from extrusion cooking. Rice is also used in making beer, rice wine, sake and vinegar.

South African rice imports are expected to increase to approximately 1 million tons in 2014. This is an increase of about 8%, from an estimated 925 000 tons imported the previous year (Anon., 2013).

2.3 Rice composition

2.3.1 Rice structure

The mature rice kernel is harvested as a covered grain (referred to as rough rice or paddy), in which the caryopsis (single, mature brown rice kernel) is enclosed in a tough siliceous hull or husk (Fig. 3). The caryopsis is a single seeded fruit, wherein the pericarp is fused to the seed (composed of the seed coat, nucellus, endosperm and embryo). The rice caryopsis is enveloped by the hull, composed of two modified leaves (lemmae), the palea and the larger lemma (Juliano & Aldama, 1937).

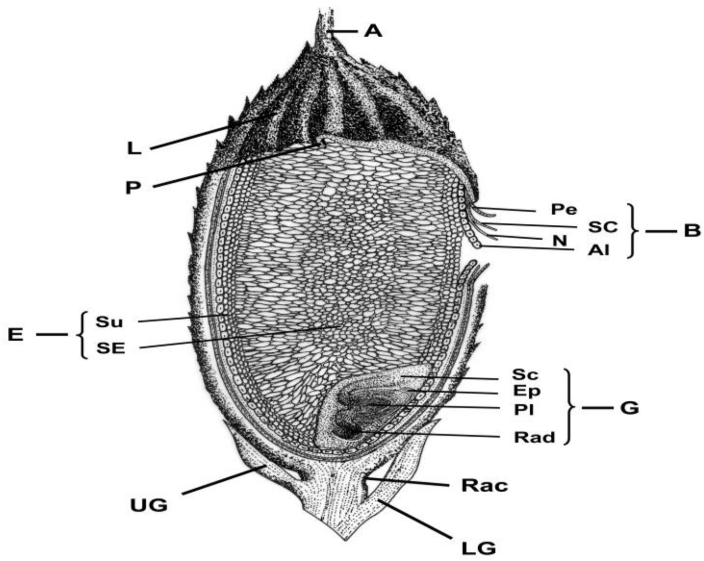

Fig. 3 Longitudinal section of the rice kernel. From top: awn (A), lemma (L), palea (P), pericarp (Pe), seed coat (SC), nucellus (N), aleurone (Al), bran (B), subaleurone (Su), starchy endosperm (SE), and endosperm (E). From bottom: lower glume (LG), upper glume (UG), rachilla (Rac), radicle (Rad), plumule (Pl), epiblast (Ep), scutellum (Sc), and germ (G). (Juliano *et al*., 1984).

2.3.1.1 Rice husk

The rice husk represents about 20% of the paddy rice grain and is composed of about 20% silica. The silica concentration is the highest in the outer layers of the husk and, together with lignin (9-20%), provides physical protection to the grain from insects and fungi (Champagne *et al.*, 2004). Cutin, a water-repellent material covering the outer layers of rice husks, makes up 2-6% of the husk (Luh, 1991). The major carbohydrates associated with the husk are cellulose, crude fibre and hemicellulose. The husk contains little to no starch, and protein and lipid contents are low (Gomez, 1979; Eggum *et al*., 1982; Pedersen & Eggum, 1983; Juliano & Bechtel, 1985; Bett-Garber *et al*., 2001). In addition to its protective role, rice husks also exhibit antioxidative defence systems that protect the ability of the mature rice seed to germinate during storage. Isovitexin, an antioxidant, has been isolated form Indica husks (Osawa *et al*., 1992). Phenolic-containing compounds were isolated from husks and these exhibited antioxidant activity, stronger than that of α-tocopherol (Ramarathnam *et al*., 1986, 1988). Ferulic, vanillic, *p*-hydroxybenzoic, *p*-coumaric, and indolacetic acids and hydroxybenzaldehyde were identified in rice husks extracts, that inhibit germination (Mikkelsen & Sinah, 1961). Plant growth regulators have also been isolated from rice husks; one such compound was nicotinamide (Takeuchi *et al*., 1975). The rice husk contains the following minerals in significant concentrations: chlorine (860 μg/g); manganese (100-290 μg/g); and sodium (67-826 μg/g) (Juliano & Bechtel, 1985). The vitamin content of the husk is limited to thiamine (0.9-2.1 μg/g), riboflavin (0.5-0.7 μg/g) and niacin (16-42 μg/g) (Juliano & Bechtel, 1985).

2.3.1.2 Rice bran

Commercial bran makes up about 10-15% of paddy rice and may contain varying proportions of polish. Polish refers to the germ and is mostly included in the bran fraction, unless removed by sieving. Rice bran is a source of protein (12-15%) and lipids (15-20%); major proteins found in bran are albumin and globulin and are considered hypoallergenic (Cagampang *et al*., 1966; Helm & Burks, 1996). A thiamine-binding protein in rice bran and germ has been isolated and characterised (Nishino *et al*., 1980; Nishimura *et al*., 1984; Shimizu *et al*., 1996).

Non-starch lipids are the most abundant form of lipid in bran and are mainly found in the aleurone, sub-aleurone and germ. They are mainly composed of neutral lipid, with lesser amounts of glycolipids and phospholipids. Starch lipids are much less and are primarily in the endosperm (Choudhury & Juliano, 1980a). Minor lipid components are sterols, tocols, tocotrienols and waxes. The typical composition of extracted, crude, rice bran oil is triglycerides (68-71%), diglycerides (2-3%), monoglycerides (5-6%), free fatty acids (2-3%), waxes (2-3%), glycolipids (5-7%), phospholipids (3-4%) and unsaponifiables (4%) (McCaskill & Zang, 1999). Phospholipids predominantly include phosphatidylcholine, phosphatidylethanolamine and phosphatidylinositol (McCaskill & Zhang, 1999). The sterol composition of rice bran consists of three 4, 4-dimethyl-sterols, seven 4-monomethylsterols, 14 4-demethylsterols and ten minor sterols (Narumi &

Takatsuto, 2000). Oryzanol, which is a phytosterol esterified to ferulic acid and found at 2% or higher levels in crude rice bran oil, has many health-promoting properties (Seetharamaiah & Chandrasekhara, 1990; Seetharamaiah *et al*., 1990; Lichtenstein *et al*., 1994; Rong *et al*., 1997). Crude bran oil contains tocotrienols at ~1,000 ppm, which are antioxidants with health-protective benefits (Tomeo *et al*., 1995; Nesaretnam *et al*., 1998). The wax component of the rice bran contains policosanols, a collection of C-24 to C-34 primary alcohols. Rice bran lipases are the major cause of bran oil deterioration. These lipases are localised in the testa and pericarp layers (Sastry *et al*., 1977). The primary enzyme has an optimum pH of 7.5 and a temperature optimum of 30°C (Rajeshwara & Prakash, 1995). Lipoxygenase found in the bran catalyses the oxidation of polyunsaturated fatty acids, containing a 1,4-pentadiene structure, such as linoleic and linolenic acids, into conjugated hydroperoxy fatty acids, which, in turn, are converted into numerous volatile compounds. Three isozymes have been characterised (Yamamoto *et al*., 1980; Ida *et al*., 1983.; Ohta *et al*., 1986; Zhang *et al*., 1996).

Starch is found in the aleurone layers of bran in the developing grain, but disappears with grain maturity (Del Rosario *et al*., 1968). It is absent in the pericarp and seed coat (Luh, 1991). Commercial bran contains starch (10-55%), contributed by the endosperm and germ. Bran is high in non-starch carbohydrates cellulose and hemicellulose, and it has been determined that water and alkali-soluble hemicelluloses contain the sugars rhamnose, arabinose, xylose, mannose, galactose and glucose, as well as some protein, hexuronic acid and ferulic acid (Mod *et al*., 1978).

The mineral content of bran and germ, with the exception of silicon, is much higher than for the other milling fractions (Juliano & Bechtel, 1985). The same could be said for the vitamin content (Juliano & Bechtel, 1985). Rice bran contains little or no vitamin A, C or D; some other vitamins that do occur, such as riboflavin and niacin, are not completely in a free form. Fresh commercial rice bran has a sweet, cereal-like aroma. During storage, objectionable odours develop due to lipid degradation through lipolytic hydrolysis and oxidation (Fujimaki *et al*., 1977; Tsugita *et al*., 1978). The main component contributing to this unpleasant aroma is 4-vinylphenol.

Removal of the bran layers along with polish, germ and a small part of the endosperm, results in milled rice composed entirely of endosperm with a starch content of 90% dry weight (Gomez, 1979; Eggum *et al*., 1982; Pedersen & Eggum, 1983; Juliano & Bechtel, 1985; Bett-Garber *et al*., 2001). Starch content increases from the surface to the core of the milled rice. Protein is the second most abundant constituent of milled rice (4-11%). Protein content is the highest on the surface of the milled rice and decreases toward the centre of the rice kernel. Crude fibre and lipid content in milled rice are low (0.2-0.5%). Phosphorus and potassium are the most abundant minerals in milled rice, whilst niacin, inositol and choline are the three predominant vitamins.

A large number of volatile compounds have been observed in uncooked and cooked milled rice. These include 13 hydrocarbons, 13 alcohols, 16 aldehydes, 14 ketones, 14 acids, eight esters, five phenols, three pyridines and six pyrazines (Yajima *et al*., 1978). The majority of these compounds are lipid oxidation compounds, which contribute minimally to fresh rice aroma, but are associated more with deterioration during storage, causing an old or stale rice aroma. Volatile sulphur compounds evolve from cooked rice and include hydrogen sulphide, methyl mercaptan, dimethyl sulphide, *n*-butyl mercaptan and dimethyl disulfide (Sato *et al*., 1976; Tsuzuki *et al*., 1978). Buttery *et al*. (1988) identified 64 volatile compounds in rice; these major contributors to rice aroma are 2-acetyl-1-pyrroline, (*E,E*)-2,4-decadienal, nonanal, hexanal, (*E*)-2-nonenal, octanal, decanal, 4-vinyl-guaiacol and 4-vinylphenol. The popcorn-like aroma of 2-acetyl-1-pyrroline is found in concentrations of 1-10 parts per billion (ppb) in non-aromatic rice and in excess of 2 parts per million (ppm) in scented rice (basmati- and jasmine-type varieties) (Buttery *et al*., 1988).

2.3.1.3 Nutrient content

Brown rice, which is the rice kernel with only the husk removed, has a higher content of all nutrients, vitamins and minerals, compared to milled rice. The vitamin concentration is 2-10 times higher in brown rice than in milled rice (Juliano & Bechtel, 1985). Brown rice protein content ranges between 4.3 and 18.2% (Gomez, 1979; Eggum *et al*., 1982; Pedersen & Eggum, 1983; Juliano & Bechtel, 1985; Bett-Garber *et al*., 2001). The nutrient distributions in the milling fractions of brown rice have been found to be uneven in the various tissues of the caryopsis (Resurreccion *et al*., 1979). More non-starch constituents are removed during milling, with fibre showing the biggest decrease, followed by a decrease of other nutrients such as fat, starch and potassium, to name but a few, with the exception of protein and zinc (Resurreccion *et al*., 1979). Approximately 80% of the non-starch lipids in brown rice are in the bran and polish, and about one third of this is in the germ (Juliano, 1972). Starch lipids are mainly in the endosperm, because they are associated with amylase (Choudhury & Juliano, 1980b). The ash distribution in brown rice (total ash content in brown rice: 1.4%) is calculated as being 51% in the bran, 10% in the germ, 11% in the polish and 28% in the milled rice (Leonizio, 1967; Juliano 1985). Iron, potassium and phosphorus have a distribution pattern similar to that of ash (Resurreccion *et al*., 1979). According to calculations, 65% of the thiamine content found in brown rice is in the bran (58% in the embryo), 13% in the polish and the remaining 22% in the milled rice. In terms of riboflavin, 39% is found in the bran (24% in the embryo), 8% in the polish and 53% in the milled rice. Similarly, the distribution of niacin is 54% in the bran (18% in the embryo), 8% in the polish and 53% in the milled rice. Milling results in the nutritional loss of approximately 76% thiamine, 57% riboflavin and 64% of the niacin of brown rice (Kik & Williams, 1945).

2.3.2 Chemical composition

The composition and properties of rough rice and its fractions are subject to varietal, environmental and processing variability (Juliano, 1972). The compositional values of rice are also determined by the state of the rice (processing), as well as the method of analysis being employed (Zhou *et al.*, 2002). Brown rice has the lowest protein content, is low in fibre and lipid content in comparison to other whole-grain cereals, e.g. wheat, corn, oat, sorghum (Zhou *et al.*, 2002). In comparison, white rice has a disproportionate loss in lipids, protein, fibre, reducing and total sugars, ash, as well as minor constituents including vitamins, free amino acids and free fatty acids, due to increased milling (Singh *et al*., 1998; Park *et al*., 2001). It is important to remember that various factors affect the composition of the rice kernel; these factors include agricultural practices and management, the soil, climatic conditions, the location on the panicle, differences in genotype, as well as processing.

2.3.2.1 Starch

Starch is the major constituent of milled rice, making up about 90% of the dry matter. Protein and lipid contents are also significant (Zhou *et al.*, 2002). The endosperm cells are thin walled and packed with amyloplasts containing compound starch granules that are evenly distributed (Azhakanandam *et al*., 2000), although they are smaller in size near the periphery of the endosperm. The two outermost cell layers (subaleurone layer) are rich in protein and lipid and have smaller amyloplasts and compound starch granules than that of the inner endosperm (Fig. 4).

Starch granules are made up from two polymers of glucose, namely amylose and amylopectin. Amylopectin molecules are highly branched, have a high molecular weight and constitute the skeleton of the starch granule (Kossman & Loyd, 2000). Amylose molecules are mostly linear, with limited branching, and co-exist with amylopectin in starch granules. Amylopectin is essential for the synthesis of a starch granule, whilst amylose is not (Champagne *et al*., 2004). Starch granules that lack amylose are referred to as being waxy or glutinous, because of their opaque appearance, due to the mutation at the waxy locus (Mizuno *et al*., 1993).

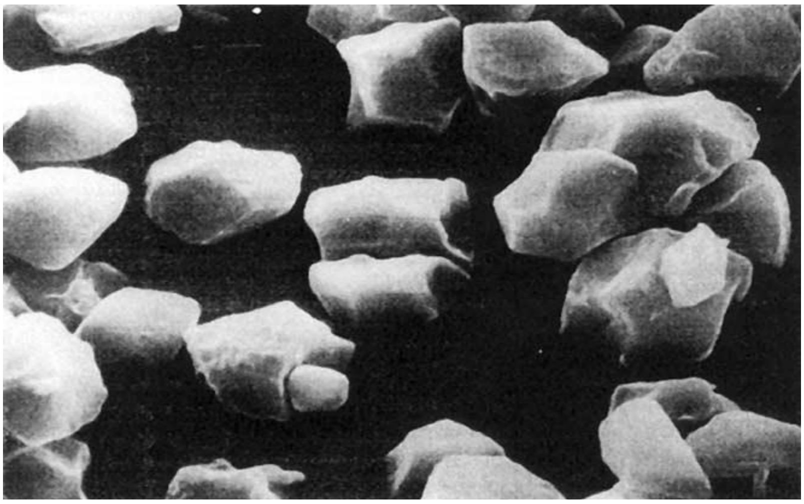

Fig. 4 Scanning electron micrograph (5000 x) of rice starch granules (Sivak & Preiss, 1998).

Starch granules contain crystalline and amorphous areas, which are described as semi-crystalline. Rice starch granules are the smallest (3-8 μm) starch particles in the plant kingdom, (Ellis *et al.,* 1998) and are polygonal and irregular in shape (Hayakawa *et al*., 1980). Compound granules have diameters up to 150 μm and form clusters, containing anything between 20 and 60 individual granules; these clusters make up most of the space within the endosperm cells. Waxy rice varieties, however, tend to have air spaces between the starch granules, which makes the endosperm opaque (Juliano, 1985).

Starch granules are formed by the accumulation of many starch molecules; these molecules consist of linear chain amylose and highly branched amylopectin. The variation in composition of rice starch is mainly caused by the proportions of these fractions in the starch granules, together with chain length distribution, as well as the frequency and spacing of branch points within the amylopectin molecule (Lu *et al*., 1997). Starch plays a pivotal role in the physical and cooking properties of rice grains through interactions with other rice endosperm components, such as proteins, lipids and water, together with interactions with other processing ingredients (Champagne *et al*., 2004). The amylose amylopectin ratio in the starch, as well as the solubility and structure of each of these glucose polymers, contribute largely to the properties of the rice grain (Champagne *et al*., 2004).

Starch granules contain some proteins and lipids. The proteins are mainly in the form of enzymes, remaining from the synthesis of starch and are accounted for by granule-bound starch synthase (Martin & Smith, 1995; Baldwin, 2001). Lipids, complexed with starch molecules, are found in starch granules. During the synthesis of the starch molecules, complexes are formed between the amylase and the lipids, as a result of the lipid molecule lodging in the cavity of the amylase helix (Morrison *et al*., 1993). The presence of lipids can substantially affect the cooking, processing and sensory properties of the starch, and the structure of the starch can affect the types of lipids present (Ozcan & Jackson, 2002).

Functional properties of starch are illustrated during the different stages of the cooking process, to transform the raw rice grain into a palatable cooked grain. The stages in the cooking process include: glass transition; gelatinisation; swelling; pasting; leaching of amylose; and lastly retrogradation (Champagne *et al*., 2004). Before gelatinisation can occur, the glassy, amorphous regions of the starch must become soft and rubbery. This process is known as the glass transition phase (Biliaderis *et al*., 1985; Slade & Levine, 1988). Water depresses the glass transition temperature to such a degree, that at higher moisture contents, the glass transition occurs at lower temperatures (Biliaderis *et al*., 1986; Slade & Levine, 1988, 1989; Mateev *et al*., 2000). As rice is generally cooked in excess water, glass transition is always depressed.

Gelatinisation is the non-equilibrium melting of the crystalline regions (Slade & Levine, 1988) and requires the glass transition (pre-softening of the amorphous regions) as a precursory step. The gelatinisation temperature of rice is an important rice property, because it correlates strongly with the cooking time and the texture of the cooked rice (Maningat & Juliano, 1978). Gelatinisation temperature is influenced by the extent of crystallinity (Slade & Levine, 1988) and the proportion of short chains present in amylopectin (Qi *et al*., 2003). Once the starch has gelatinised, the starch granules begin to swell and in the absence of shear, can swell to many times their initial volume, whilst maintaining their integrity (Parker & Ring, 2001). Accompanying the swelling, is the leaching of the amylose molecules into the continuous phase (Bhattacharya *et al*., 1972a, 1978; Chinnaswamy & Bhattacharya, 1986; Sandhya Rani & Bhattacharya, 1989; Jacobs & Delcour, 1998; Nguyen *et al.*, 1998; Mizukami *et al.*, 1999; Ramesh *et al.*, 1999; Fitzgerald *et al*., 2003). The amount of amylose, that becomes soluble in hot water, influences the cooked rice texture, more than the total amount of amylose (Chinnaswamy & Bhattacharya, 1986; Sowbhagya *et al*., 1987; Ramesh *et al*., 1999). Solubility of amylose is affected by the amylose structure, amylose entanglement with gelatinised amylopectin or amylose complexes with lipids. Differential scanning calorimeter (DSC) is the preferred method for the measurement of starch gelatinisation (Nakazawa *et al*., 1984; Shiotsubo & Takahashi, 1984; Noda & Wickramasinghe, 2008; Acquistucci *et al*., 2009; Wani *et al*., 2010). The gelatinised starch contains no crystalline regions, but under certain storage and temperature conditions the molecules can re-associate into an ordered structure, known as retrogradation (Baik *et al*., 1997).

Retrogradation describes the rapid recrystallisation of amylose and the slow re-crystallisation of amylopectin (Slade & Levine, 1987). The degrees of retrogradation, as well as the nature of the newly formed crystals, are dependent on time and temperature of storage, the source of the starch, as well as the presence of other molecules in the system (Slade & Levine, 1987; Baik *et al*., 1997).

Essentially the re-crystallisation of amylose is the rapid formation of double helices in parts of the amylose chains, followed by the aggregation of those helices (Gidley, 1989). The first stage of retrogradation depends on the amylose content of the rice as well as the amount of amylose that is free, rather than complexed with lipids (Baik *et al*., 1997; Yao *et al*., 2002). Hot-water soluble components of rice starch, with high molecular weight, promote retrogradation more than lower molecular weight polymers; this suggests that the molecular weight distribution of the amylose contributes significantly to the first phase of retrogradation (Tsai & Lii, 2000). Retrogradation, due to amylose, is not reversible at temperatures less than 100°C (Miles *et al*., 1985). The second stage of retrogradation is the re-crystallisation of short amylopectin chains (Baik *et al*., 1997). Studies suggest that the chain length distribution of amylopectin contributes to the difference in the degree of retrogradation by amylopectin (Lu *et al*., 1997; Fredriksson *et al*., 1998; Silverio *et al.*, 2000; Tsai & Lii, 2000, Yao *et al*., 2002).

The interaction of amylose with amylopectin increases the rate of amylopectin retrogradation (Yao *et al*., 2002). Retrogradation, due to amylopectin, is reversible if the retrograded gel is exposed to temperatures greater than the gelatinisation temperature of crystalline amylopectin (Lu *et al*., 1997). The functional properties of rice differ greatly among different varieties of rice.

2.3.2.2 Lipids

Lipids are not as abundant in rice as carbohydrates and proteins, but they significantly contribute to nutritional, sensory and functional qualities (Champagne *et al*., 2004). Lipids in rice are present in the form of spherosomes, or lipid droplets, having diameters of < 1.5 μm in the alearone layer, <1 μm in the subaleurone layer and 0.7 μm in the germ of the rice grain (Juliano, 1983). Cereal lipids are chemically diverse and can be classified as neutral lipids, glycolipids and phospholipids (Mano *et al*., 1999). The lipid content of rice is concentrated in the bran fraction and can contribute as much as 20% by mass, in the aleurone layer and the bran of the rice kernel (Bechtel & Pomeranz, 1977, 1978). Rice lipids can be further classified, according to their distribution and association, as either starch lipids, which are associated with starch granules (Choudhury & Juliano, 1980a; Juliano, 1983), or non-starch lipids, which are distributed throughout the grain (Choudhury & Juliano, 1980a), but concentrated in the rice bran.

Starch lipids represent a small proportion of the total lipid composition of rice, but may play a role in starch synthesis and appear to make a major contribution to starch functionality (Morrison, 1995). Starch lipids primarily consist of lysophospholipids and free fatty acids (Morrison, 1988). Starch lipids of waxy milled rice have more free fatty acids and fewer lysophospholipids than starch lipids of nonwaxy milled rice (Choudhury & Juliano, 1980b). Lysophosphatidylcholine is the major phospholipid of starch lipids, followed by lysophosphatidylethanolamine, and sterol glycosides are the major glycolipids (Hirayama & Matsuda, 1973). Major fatty acids of nonwaxy milled rice starch lipids are palmitic and dilinoleic together with a lesser amount of oleic acid (Choudhury & Juliano, 1980b). Starch lipids have less oleic acid and more palmatic acid than non-starch lipids. Starch lipids of milled non-waxy rice consist of palmitic (35%), oleic (14%) and linoleic acid (46%) (Choudhury & Juliano, 1980b).

Non-starch lipids are the most abundant form of lipid in rice and are found in the aleurone, subaleurone and germ of brown rice, with a small amount in the husk of paddy (rough) rice. It is composed primarily of neutral lipids, with lesser amounts of glycolipids and phospholipids (Champagne *et al*., 2004).

2.3.2.3 Protein

Rice protein is an important source of nutrition for approximately 50% of the world's population, for whom rice is a staple diet (Champagne *et al*., 2004). The protein content for brown rice ranges between 6.6 and 7.3%, and between 6.2 and 6.9% for white rice, and is relatively low when compared to other cereal grains (Singh *et al*., 1998).

Rice proteins are extremely insoluble, because of intermolecular disulfide linkages and high molecular weights of the major protein glutelin (Cagampang *et al*., 1966; Sawai & Morita 1968; Tecson *et al*., 1971). Rice protein has an inhibitory effect on the swelling of rice starch granules (Marshall *et al*., 1990). Measuring the interaction of protein and starch in a model system, it was found that stickiness of whole cooked rice was positively correlated with the binding ratios of the rice protein, oryzenin, to starch, amylose and/or amylopectin (Chrastil, 1990). Cooked rice stickiness increased with the disruption of disulfide linkages in the protein component (Hamaker & Griffin, 1990, 1993; Hamaker *et al*., 1991). Proteins found in the outer layers of the rice kernel, tightly bound to starch, were found to be responsible for reducing the pasting and crystallising capacities of the starch (Yang & Chang, 1999).

The embryo and aleurone layer in rice has the highest protein content, followed by the endosperm. Hence, the protein content decreased linearly with the increase in polishing (step in milling process), due to the prevalence of protein in the peripheral layers of the kernel (Palamiano *et al*., 1968). Rice protein has a significant influence on the structural, functional and nutritional properties of rice. Rice protein plays a major role in determining the texture, pasting capacity and sensory characteristics of rice (Champagne *et al*., 2004).

2.4 Physical properties of rice

According to Bhattacharya (2011), the physical properties of rice denote the following: grain size and shape; density and bulk density; colour; angle of repose; hygroscopic properties; thermal properties; mechanical properties; and grain chalkiness. One cannot look at these properties in isolation; variety, moisture content, degree of milling, temperature and potentially the age of the rice grains will have a direct influence on the above-mentioned properties. Since rice can exist in three stages, namely paddy, brown rice and milled rice (Fig.1), these properties need to be evaluated for all the forms of rice.

2.4.1 Grain size and shape

The length, breadth and thickness of rice vary widely among all rice varieties, excluding American varieties (Bhattacharya, 2011). Bhattacharya *et al*. (1972a) showed that some dimensions in the rice grain had certain interesting interrelations. They found that grain length was an independent variable, not related to the other size parameters; the weight parameter, on the other hand, was related to the total volume and dimension of the grain, whilst the breadth (width) was well correlated to the thickness of the grain, in both the paddy and rice.

The dimensions of the inner rice kernel were greatly determined by the dimensions of the outer grain (paddy) dimensions and research found that generally most rice grains were just over 0.3 mm thinner than their corresponding paddy grain. The length:breadth ratio of the rice kernel was usually 0.35 lower than that of its corresponding paddy grain, and the yield of rice from paddy grains was approximately 73% (Bhattacharya *et al*., 1972a).

Similarly, all dimensions of milled or brown rice were closely related to the dimensions of the corresponding paddy as well. Slender grains (2.3 mm or less in breadth) were just over 0.7 mm thinner than their corresponding paddy, whilst broader grains were 0.81 mm thinner than their corresponding paddy. The difference in the breadth of paddy and milled rice can be ascribed to the husk kernel gap, which varies between 0.55 and 0.6 mm. An interesting observation was that brown rice, with a breadth of over 2.35 mm, almost invariably had a white belly (refer to 1.4.7), whilst any breadth below this, usually had no white belly (Bhashyam & Srinivas Aiyangar, 1981; Murugesan & Bhattacharya, 1994).

Rice can be classified according to dimension. The United States Department of Agriculture (USDA), the International Rice Research Institute (IRRI) and the Food and Agriculture Organisation (FAO) have prescribed a dimensional classification based on length (extra long, long, medium and short) and shape (slender, medium, bold and round). This classification is, however, of limited use and can mainly be used for research purposes or marketing purposes when grading information is required (Bhattacharya, 2011).

American rice has been deliberately bred to have standardised dimensions, and one cannot compare these dimensions with the prevailing dimensions of rice in the world in general. American rice is classified into 3 classes, namely long, medium and short grain, but this classification is not only based on the length dimension alone, as often wrongly understood in industry, but in fact also denotes a combination of a number of characteristics, such as grain length, shape, amylose content, alkali score and gelatinisation temperature (Adair *et al*., 1973; Webb, 1985). This classification is a comprehensive quality indicator, not only in terms of appearance but also the cooking and processing qualities of rice. Many rice-exporting countries in the world often employ the same or similar nomenclature for exporting purposes, but this is a misnomer for the names “long grain” or “medium grain”. As the rest of the world does not use this classification, due to the large variation in dimensions, several attempts have been made to compile a suitable classification system, but none has been officially adopted.

2.4.2 Colour

There is little variation between varieties, when it comes to the colour of paddy and its corresponding brown and milled rice. Milled rice usually has the least colour variation, being mostly white, but can be dull at times. Brown rice shows little more variation between varietal colours, but in some varieties (found in the hills of India) it may even have dark brown to black pericarps. The colour of paddy is usually a yellow or golden colour, but here too exceptions can be found (Bhattacharya, 2011). Rice colour is typically measured by making use of a colorimeter.

2.4.3 Density and bulk density

The density of a large number of rice varieties has been determined by liquid displacement. The density (1.452 g/mL) was found to be relatively constant in all the milled rice samples analysed. Brown rice density was found to be marginally lower than expected (Kunze *et al*., 2004). The density of paddy was much lower and also varied between varieties. The paddy density also showed a relationship to the grain shape; variation encountered can be attributed to the variable void or airspace between the outer hull and the inner rice kernel. This airspace was found to be larger in the short and round varieties, than in the medium or slender varieties. Bulk density was also determined and substantial variation was found among the varieties tested (Bhattacharya *et al*., 1972b). This variation was found in both paddy (0.563-0.642 g/mL) and milled (0.777-0.847 g/mL) rice. This variation in bulk density was found to be related to grain shape, specifically the slenderness (length and breadth ratio), but was also influenced by the grain's frictional property. Slender grains have a lower bulk density and round grains a higher bulk density, but this is also influenced by the grain's frictional property.

Rice has a relatively high moisture content when harvested and is subsequently dried to an acceptable level before storage. Changes in the moisture content of rice have an effect on its density, bulk density, porosity and frictional value and the changes are especially noticeable in brown rice and paddy. In brown rice, the density and bulk density decrease when the moisture content increases (Bhattacharya *et al*., 1972b). For every 1% increase in moisture content, a linear decrease of 0.005 g/mL in density is observed, whilst a 0.01 g/mL linear decrease in bulk density is observed. The porosity of the rice also increases, which leads to an increase in the angle of repose. Paddy, on the other hand, shows an increase in density and bulk density, with the increase in moisture content. For every 1% increase in moisture content, an increase of 0.0075 g/mL is observed in density and a 0.0045 g/mL increase is observed in bulk density. The angle of repose is also increased, while the friction rate mainly stayed unchanged. The increase in density and bulk density is due to the internal void between the kernel and the husk, lending enough space to the kernel to expand freely, without disturbing the outer volume. Thus, the grain weight increases, but the volume remains unchanged, leading to the increase in density. Hydration of around 13-30% moisture content shows a 30% increase in grain volume, but only a 9% increase in the paddy (Bhattacharya *et al*., 1972b). The moisture content also increases the dimensions in both paddy and brown rice.

2.4.4 Hygroscopic properties

Rice is hygroscopic and, as is the case with other cereals, its moisture content varies naturally (Bhattacharya, 2011). Two terms are important when it comes to describing the hygroscopic properties of rice: equilibrium moisture content and equilibrium relative humidity. Equilibrium moisture content (EMC) refers to the moisture content of grain or a mass of grains, when exposed to a given atmosphere of known relative humidity for a period of time, to reach equilibrium. Equilibrium relative humidity (ERH), on the other hand, refers to the relative humidity of the inter-granular air, in equilibrium with a mass of grain, at a given moisture content (Bhattacharya, 2011). The ERH is very important when it comes to the storage of rice. Typically, when stored at low moisture, low ERH is achieved; as soon as the moisture increases, so does the ERH, which will favour pest activity, attracting insects, fungi and mites. Different rice components equilibrate to different moisture contents: the husk has the lowest EMC; milled rice (endosperm) the most, and brown rice an intermediate EMC. Varieties also differ in their EMC. EMC values also differ between whether the grain attains the equilibrium while adsorbing or desorbing; this property indicates that the moisture content of different grains in a lot may not only show grain-to-grain variation, because of difference at the time of harvest, but may continue to do so even after equilibration. The EMC value changes with temperature; as soon as the temperature increases, so does the ERH for that moisture content, and vice versa (Bhattacharya, 2011).

2.4.5 Mechanical properties

Mechanical properties of the rice grain include the following: tensile; compressive and bending strengths; modulus of elasticity and toughness; and grain hardness (Bhattacharya, 2011). A sound, mature rice grain has sufficient tensile, compressive and bending strength, not to be harmed by normal mechanical processing steps. Rice grains that have fissured due to moisture stress, on the other hand, are weak and easily harmed by the normal mechanical processing steps. The moisture content has a direct influence on the mechanical strength of the rice grain (Kunze *et al*., 2004). In a study conducted by Perdon *et al*. (2000), it was observed that mechanical properties, such as toughness, modulus of elasticity, tensile and compressive strength, and hardness of rice, all had higher values in the glassy region of the rice kernel, but the magnitude of specific heat, specific volumes and expansion coefficient were much lower at glassy, compared to the rubbery region. These changes in the physical properties at the glass transition temperature may have strong bearing on the damage that may occur to the rice grain upon drying. Rice grain hardness for milled rice is in the region of 7-10 kg/grain; chalky grains, on the other hand, are softer and the hardness value can be as low as 3-4 kg/grain. The relative breaking hardness of brown and milled rice is roughly half that of paddy, the hull probably providing a cushioning effect in the latter (Kamath *et al*., 2008).

2.4.6 Thermal properties

The thermal properties of rice can be described in its specific heat, conductivity and diffusivity (Kunze *et al*., 2004). Rice is not a good conductor of heat, but conduction increases with the increase of moisture, at a given temperature. Rice expands upon heating and shrinks upon cooling, although these changes are minute.

2.4.7 Chalkiness

Rice grains often have areas which are opaque in comparison to the rest of the translucent grain appearance; these areas are referred to as grain chalkiness. Grain chalkiness is due to the loose starch-granule packing at the chalky area, within the grain, containing some air spaces; these loosely packed granules scatter light and thus, cause the appearance of opacity, i.e. chalkiness. Grain chalkiness can be classified into four types: white centre or core; white belly; milky white; and opaque (Ikehashi & Khush, 1979). White core grains contain a chalky area at the grain centre, whilst white belly grains are those grains with the chalkiness in the germ side. In both cases the chalkiness may vary from a tiny spot to almost covering 75% or more of the grain area. Chalkiness in the milky white grain is spread to the entire grain, except the peripheral part. Opaque grains are mostly immature grains. White core and white belly are the most important of this classification and are usually indexed by assigning scores (0-9), depending on the grain area covered by chalkiness (Ikehashi & Khush, 1979). The origins of white core and white belly are clearly distinguished; white core chalkiness is genetically controlled, as some varieties inherently have white core grains whilst others do not, while white belly is dependent on grain breadth. All grains over 2.8 mm in breadth invariably have white belly; grains with a width between 2 and 2.8 mm sometimes have white belly; whereas grains with a breadth smaller than 2.0 mm never have white belly. Chalkiness is, however, also related to growing temperature; high night temperatures during grain filling have repeatedly been shown to cause chalkiness (Stansel *et al*., 1961; Bangwaek *et al*., 1994; Resurreccion & Fitzgerald, 2007; Cooper *et al*., 2008). Chalky grains are softer than translucent grains (Sandhya Rani & Bhattacharya, 1989; Kim *et al*., 2000) and they have higher room-temperature water absorption (Bhattacharya *et al*., 1979; Kim *et al*., 2000). Chalkiness has a direct effect on quality attributes. Patindol & Wang (2003) found that starch from chalky kernels has less amylose and showed an increase in amylopectin with very short chains, and a decrease in amylopectin with long chains. The starch also exhibited a greater crystallinity, more breakdown and less setback in their pasting pattern, with a marginally higher gelatinisation temperature and enthalpy. Similar results were found by Sandhya Rani and Bhattacharya (1989) and Lisle *et al*. (2000).

2.5 Rice processing

Rice paddy needs to be milled to be in a suitable form for human consumption. This is collectively achieved by the milling process. The milling process consists of numerous steps: paddy cleaning; husk removal; bran removal; classification; and packing (Champagne *et al*., 2004).

2.5.1 Cleaning of paddy

Several different impurities have to be removed from the paddy before the milling process can commence. The harvesting methods, as well as the specification of the milled rice product, determine the degree of cleaning required. The cleaning process involves a number of steps based on physical differences between rice and various impurities. These steps include: size; density; magnetic conductance; frictional force; and optical characteristics (Champagne *et al*., 2004).

2.5.2 Husk removal

Brown rice is produced by removing the husk from the rice kernel. This is performed in two interrelated stages. During the first stage of paddy husking, the husk is broken loose from the paddy kernel and removed from the rice. Removing the husk from each paddy kernel is not always successful after the first attempt and may require a second stage of husk removal, where the unhusked grains are fed back to the husker (Champagne *et al*., 2004).

2.5.3 Bran removal

Once all the husks have been removed, the next step is to remove the germ and the bran layers from the brown rice underlying starchy endosperm. The objective is to do this without breaking the rice kernels. A combination of two milling actions is used to obtain the best results; the first layers of the bran are typically removed using abrasive milling (low pressure, high-power efficiency). The bran removal is then completed by applying pressure and movement between the grains, which enables the force of friction to tear away bran layers (Champagne *et al*., 2004). The combination of these methods produces rice that has a superior appearance, as well as optimum total milled-rice yields.

2.5.4 Classification

Once the rice has been milled, it is necessary for the broken grains to be separated from the whole kernels. This process is referred to as classification, and takes place through mechanical and electronic sorting. The first method uses the concept of different grain lengths to separate the kernels in a high-capacity grading sifter and an indented cylinder grader. Depending on the customer's specification, the broken grains may be blended with unbroken kernels, according to a specific ratio (Champagne *et al*., 2004).

The electronic sorting removes non-magnetic objects that are similar in size and density to whole or broken rice kernels, and are difficult to remove through mechanical means. Colour sorters are used to remove foreign objects on the basis of their appearance (Champagne *et al*., 2004). Before packing can commence, the rice is passed over an in-line metal detector, which will remove all non-ferrous metals that may still be present in the rice.

2.5.5 Milling quality

The milling quality refers to the way that paddy responds to the milling process and is an important milling parameter of rice. The amount of brown rice produced after husking/shelling is referred to as the brown rice yield or outturn. The amount of final milled rice or white rice produced, which also includes the broken grains, is referred to as the total yield or the total milled rice yield or outturn. The amount of unbroken grain produced is referred to as the head yield or the head milled rice yield or outturn. The brown rice yield, total milled yield and the head yield constitute the milling quality of rice (Bhattacharya, 2011).

3. Parboiled rice

3.1 Introduction

Milled rice can be found in two forms, namely raw and parboiled. Parboiling can be described as a hydrothermal process in which the crystalline form of starch is changed into an amorphous state as the result of irreversible swelling and fusion of the starch. The changes are brought about by the soaking, steaming, drying and milling of the paddy rice (Bor, 1991). Parboiled rice is mainly found in South Asia (Indian subcontinent), where approximately 90% of the world's parboiled rice is produced and consumed. Globally about a fifth of the world's rice is parboiled (Bhattacharya, 2004).

3.2 History

Parboiled rice is believed to have originated from ancient India (Ghose *et al*., 1960; Tata, 1962). Research suggests that parboiled rice has been an established product for more or less two thousand years (Srinivas Aiyangar, 1985; Achaya, 1998a, b). Exactly how and why this process came about is a topic that can be debated, but it can be accepted that this continued practice is due to the reduction in milling breakages, easier de-husking of paddy, together with the fact that the people of South Asia have a preference for high amylose rice that cooks hard and fluffy. It is speculated that some of the South Asians were not satisfied with the hard and fluffy characteristic that only high amylose rice presented and wanted something that was even further hardened by the process of parboiling (Bhattacharya, 2004).

Parboiled rice is nutritionally superior to raw milled rice, especially in its vitamin B (especially thiamine) content. This was first noted in 1907 by Braddon, when it became evident that Chinese immigrants in Malaya (who mostly consumed raw milled rice) suffered from beriberi, while the Tamil (Indian) immigrants (who mainly consumed parboiled rice) did not. Many studies were subsequently conducted to prove that the consumption of parboiled rice reduced the occurrences of beriberi (Fletcher, 1907; Fraser & Stanton, 1909; Vedder, 1913; McCarrison & Norris, 1924; Taylor *et al.*, 1928). Aykroyd (1932) used a bioassay with birds, while Acton (1933) used a chemical method that finally proved that milled parboiled rice contained much more thiamine than milled raw rice. This discovery made milled parboiled rice a favourite among those in the industry, nutritionists and researchers alike (Bhattacharya, 2004). Milled parboiled rice was internationally favoured as a preventative measure against beriberi. With all the focus on parboiled rice at the time, some other properties were also discovered, namely, a vast reduction in grain breakages during milling, as well as changes in cooking quality. These three quality aspects were significantly studied in the 1930s and 1940s.

With the growing popularity of milled parboiled rice, the need arose to modernise the primitive parboiling industry; new parboiling processes were developed and patented, but the processes proved too sophisticated and the new industry too small to be of any relevance to the vast traditional parboiling industry in South Asia (Bhattacharya, 2004). The biggest problem presented by the new processing methods was that, if the paddy was soaked in ambient or warm water for prolonged periods, the paddy would start to ferment and develop a characteristic offensive odour (Ghose *et al*., 1960; Tata, 1962). Many methods to combat this microbial fermentation were investigated (cf. Paul, 1954; Desikachar *et al.*, 1955; Mecham *et al*., 1961; Jayanarayanan, 1964; Pillaiyar, 1977; Vasan & Kumaravel, 1982;) but they all proved to be impractical. Finally a hot soaking system was adopted; this system prevented the fermentation and unwanted odour formation, by treating the paddy with hot water (> 55°C) and subsequent recirculation of the heated water, to prevent temperature stratification (CFTRI, 1969).

3.3 Parboiled rice consumption

South Asia is the biggest net producer and consumer of parboiled rice in the world. Brazil, followed by the USA, are the second and third largest producers, respectively, of parboiled rice globally (Champagne *et al*., 2004). Thailand has been a top exporter of parboiled rice for a long time, and continues to be one of the largest exporters, i.e. shipping close to 2 million tons of milled parboiled rice annually to West Asia, Europe, USA, Africa and some other Asian countries (Champagne *et al*., 2004). Approximately 40 million metric tons of milled rice are traded internationally, and of this total only 5-6 million metric tons are parboiled rice (Larry Soobramoney, Phoenix Commodities, 2014, personal communication). The main exporters of parboiled rice are Thailand, India and the USA, whilst West Africa, Southern Africa, Saudi Arabia and Bangladesh are the major importers. Large amounts of parboiled rice are consumed in both South Africa and Zimbabwe, all of which is obtained through imports as no rice is grown in Southern Africa (Champagne *et al.,* 2004). Exactly how the preference for parboiled rice in South Africa came about is unclear, but it could be related to some of the benefits brought about by the parboiling process itself, namely the higher nutritional value and resistance to spoilage by insects and mold, and possibly also the fact that parboiled rice's shape remains intact during prolonged cooking. Other possible factors could include increased disposable income, growing population and increased interest of consumers in diversifying their meals. The total amount of rice to be imported to South Africa, for 2014, was estimated at approximately one million metric tons, whilst the total worldwide production for 2013/14 was estimated at 700 million metric tons. Approximately 70% of the rice imported to South Africa comes from Thailand, making Thailand the major exporter to South Africa. Of all the rice imported to South Africa, 98% is parboiled (Larry Soobramoney, Phoenix Commodities, 2014, personal communication).

When comparing rice production to other grain cereals in the world, rough rice production can be seen as approaching the same volumes as that of maize and wheat.

3.4 Processing

The parboiling process can be described in four steps: soaking; heating; drying; and milling.

3.4.1 Soaking

Soaking in potable water is required to hydrate the paddy sufficiently, to ensure its gelatinisation in the heating step of the process (Champagne *et al*., 2004). The hydration rate increases with the increase in water temperature (Mecham *et al*., 1961; Bandopadhyay & Ghose, 1965). Two distinct patterns of hydration were noted by Bhattacharya and Subba Rao (1966a). When soaking the paddy in water that is below the gelatinisation temperature, the water absorption of the paddy is low, but eventually comes to equilibrium at ~30% moisture (wet basis [wb]). When soaking the paddy at temperatures above the gelatinisation temperature, the water absorption increases exponentially after an initial lag phase; this increase is due to the gelatinisation of the starch. Once the grain moisture exceeds ~30-32% the husk splits open, because the husk is no longer able to contain the expanded endosperm inside it and this leads to even more hydration. The result is then leaching and deformation of the grain. Upon soaking the paddy, the density increases due to the void that is present between the endosperm and the husk, that allows enough space for the endosperm to expand, without altering the volume of the paddy. The volume expansion associated with the paddy rice is more or less 10%. In terms of porosity and pressure the following changes were noted by Bandopadhyay and Ghose (1965): the porosity decreased marginally from 0.5 to 0.48 in one variety during soaking up to 75°C, but it fell significantly to 0.42 when soaked for 3 h at 80°C; the pressure drop was very small when soaking occurred at > 75°C, but it became perceptible at 80°C.

When determining the soaking conditions, Bhattacharya (2004) strongly believes that the hydration of paddy rice is affected by many variables, such as surface area, volume of grain and texture of husk. Due to these variables it seems better to determine soaking conditions empirically, rather than by calculation. The simplest way to determine optimal soaking conditions is to soak paddy at different temperatures for different times, drain and steam for 5-10 minutes, dry and mill. The minimum time at the highest temperature, at which the husk does not split open and the milled rice shows no sign of opaque central core, can be considered to be the optimum time and temperature. In practice, two broad alternatives can be considered. The first is no or little control over soaking time when the paddy is soaked at less than 60-65°C, as the equilibrium moisture content at these temperatures does not exceed 30-32°C (wb) (Bhattacharya & Subba Rao, 1966a). This method does have disadvantages, in the fact that too much time may be used and that fermentation can occur if the temperature is too low. The second option is to soak at high water temperatures, but here, too, there are disadvantages, namely over-soaking and consequent splitting of the husk with leaching and grain deformation. Due to the time benefit of the latter method, it has been found that soaking at relatively high temperatures can be done in the following three ways: below 75°C the soaking time should be strictly monitored until the moisture content reaches 30-32 %, upon which the water must be drained out, once this has been done, the paddy must be tempered to equalise its moisture (Mecham *et al*., 1961); paddy should be soaked at ~70°C with strict time control; soaking should commence at ~75°C and the batch of paddy allowed to cool naturally during soaking. The efficacy of the last mentioned method depends on the gelling temperature (GT), specific to the variety being treated (Biswas & Juliano, 1988). When soaking the paddy, it is not essential that it be soaked to saturation, before parboiling can commence; approximately 24% moisture that is evenly spread throughout the grain is enough to bring about gelatinisation of starch at normal atmospheric steaming (Ali & Bhattacharya, 1982; Pillaiyar *et al*., 1993; Velupillai, 1994). Applying air pressure to paddy during soaking has been found to reduce soaking time (Velupillai & Verma, 1982; Jagannadha Rao *et al.,* 1997). Kulkarni and Bal (1984, 1986) confirmed that de-aerating paddy before commencing with soaking also increased its hydration rate. Grains from different tillers or at different positions within a panicle hydrate at slightly different rates; this was found to be the case with younger grains as well (Pillaiyar *et al*., 1998). Thus, the variation of grains in a paddy is a hazard when soaking. It has been found that the initial grain moisture does not, however, affect the subsequent hydration significantly (Ali & Ojha, 1976).

3.4.2 Heating

As mentioned above, the purpose of heating or steaming the soaked paddy is to gelatinise the starch. Bhattacharya and Subba Rao (1966a) found that if the grain hydration is adequate and even, steaming for only two minutes at atmospheric pressure will be sufficient to gelatinise the starch. The amount of heat the paddy is exposed to during this step has a direct influence on the milling quality of the paddy. The ability of the parboiled paddy to withstand the adverse conditions of drying without increasing cracking rises with the increase in heat treatment (Champagne *et al*., 2004). During heating or steaming the husk splits open; this is caused by the swelling due to absorption of adhering water or condensate; however, no splitting occurs when the moisture content within the grain remains low. Although, in practice steaming of the paddy, as a means of heat transfer, is used almost exclusively, other methods can also be employed, for example, ohmic heating (LSU, 1998) and electrical resistance (Vasan & Ganesan, 1981), to name but two.

3.4.3 Drying

Once the paddy has been parboiled, it contains about ~35-38% absorbed grain moisture, as well as ~5% adhering water. To ensure a product that is safe for milling and storage, the moisture content needs to be reduced as soon as possible to 12-14% (Champagne *et al*., 2004). The method employed during drying of the paddy greatly determines the milling quality of the product. It has been found, however, that when wet parboiled paddy is dried in the sun or with hot air, no damage (cracking) occurs, until the moisture content drops to ~16%, which invariably leads to an increase in breakages during milling (Craufurd, 1962, 1963; Sluyters, 1963; Bhattacharya & Indudhara Swamy, 1967). These cracks do not appear in the grain during drying but only afterwards, when the rice has been left to cool for some time. The solution to the problem is to dry the paddy as fast as possible to a moisture content of 16-18%, and then to temper the rice for 4-8 h; this allows the steep moisture gradient to relax. After this, the drying process can be completed without any adverse effects to the paddy (Bhattacharya & Indudhara Swamy, 1967).

Various parboiling processes can be distinguished, namely conventional (soak-drain-cook-dry), pressure (low moisture) and dry heat parboiling (Bhattacharya, 2004). For the purposes of this study, only the conventional parboiling process will be considered, as most of the rice imported to South Africa is rendered by this method.

Conventional parboiling is the most common and widely used process, and can briefly be described as follows. Paddy is soaked in water at a suitable temperature that can range from anything between ambient (2-3 days) to about 70°C (3-4 h) until a moisture content of approximately 30% (saturation) is achieved. The paddy is drained and then steamed (most common practice), until the starch is gelatinised. Steaming can take place either at atmospheric pressure (open steaming) or under elevated pressure (0.5-0.2 kg/cm^2 gauge pressure) (Bhattacharya, 2011).

3.5 Properties of parboiled rice

3.5.1 Rice constituents altered during parboiling

The properties of rice are changed significantly during the parboiling process. These changes are brought about by the grain constituents that undergo changes during the parboiling process (Champagne *et al*., 2004). The changes brought about during soaking can be described as being due to enzymatic activity, possible migration of small molecules, as well as husk opening (Bhattacharya, 2011). The soaking of paddy is akin to the initial phase of germination and a large amount of enzymatic activity takes place. Enzymatic conversion of sucrose into reducing sugars and *de novo* production of sugars and amino acids, has been reported (Ali & Bhattacharya, 1980). The extent of these changes is directly related to the soaking temperature. These changes in amino acids and sugars cause the discolouration associated with parboiled rice (Bhattacharya, 2011). Other changes brought about include an increase in reducing sugars (Anthoni Raj & Singaravadivel, 1980), as well as an increase in phenolic compounds (Anthoni Raj *et al*., 1996). Xavier and Anthoni Raj (1996) reported increased activities of diverse enzymes and the increased excretion of chloride during soaking (Anthoni Raj *et al*., 1996).

Another change, thought to be brought about during the soaking process, is that of the inward migration of small water-soluble molecules from the bran layer into the endosperm, such as B vitamins, sugars and certain minerals (Bhattacharya, 2011). During the soaking process, depending on the soaking conditions, some of the colour in the husk is dissolved into the water, also contributing to the discolouration, with either the inward migration or as a result of the husk splitting open and the kernel being directly exposed to the discoloured water (Bhattacharya, 2011).

During steaming of soaked paddy, fundamental changes occur in parboiled rice. Steaming disrupts the three main constituents (starch, lipids and proteins) present in rice, but the transformation of starch is the key change responsible for many of its properties. Starch undergoes two sequential changes during parboiling, namely gelatinisation followed by reassociation (retrogradation). During gelatinisation the birefringence of the starch is lost and the A-type X-ray diffraction of raw rice is destroyed (Raghavendra Rao & Juliano, 1970). Upon reassociation, the starch forms complexes with lipids. The total amylose content remains mostly unchanged (Raghavendra & Juliano, 1970; Ali & Bhattacharya, 1972), although evidence of thermal breakdown of starch was obtained (Mahanta & Bhattacharya, 1989). During the fractionisation of parboiled rice starch with gel-permeation chromatography, the proportion of the high molecular weight fraction progressively decreased, whilst the low molecular weight fraction increased with the increase in steam pressure.

Protein bodies in parboiled rice are ruptured and its solubility reduced (Raghavendra Rao & Julliano, 1970). The protein content of rice, either brown or milled, is unaffected by the parboiling process (Bhattacharya & Ali, 1985).

Research has showed that milled parboiled rice contains less fat than milled raw rice, after equivalent degrees of milling (Subrahmanyan *et al*., 1938). Mahadevappa and Desikachar (1968) showed that in native brown rice, the oil is mostly contained in distinct bodies in the aleurone layer and germ, but these bodies were disrupted and moved into an oil band after parboiling. Outward migration of the oil must be related to the rupture of these oil globules, as the amount of oil on the grain surface has been shown to be higher after parboiling.

3.5.2 Characteristics brought about by parboiling of rice

Milled parboiled rice is slightly (~5%) shorter and broader than milled raw rice; this could be attributed to some realignment of the cooked grain, brought about in the steam phase of the parboiling process (Bhattacharya & Ali, 1985; Sowbhagya *et al*., 1993; Lu & Lii, 1996). The milled parboiled rice grains also become glassy and translucent, in comparison to their raw rice counterpart, and any chalky areas within the raw rice become translucent with parboiling. It is speculated that the gelatinised starch granules and disrupted protein bodies adhere to each other to form a compact mass, reducing the light scattering at the boundaries of the granules (Raghavendra Rao & Juliano, 1970). The parboiled rice grain also becomes harder than its non-parboiled counterpart and its hardness is proportional to the severity of the heat treatment during processing (Raghavendra Rao & Juliano, 1970; Kimura *et al*., 1976; Pillaiyar & Mohandoss, 1981; Islam *et al*., 2001). The parboiling process also renders rice discoloured, becoming light yellow to amber in colour. The discolouration is mainly caused by non-enzymatic browning brought about by the Maillard reaction (Charlton, 1923; Houston *et al*., 1956; Mecham *et al*., 1961; Jayanarayanan, 1964). The reducing sugars and amino acids that are formed in the soaking process, in combination with the heat treatment during the steaming phase are the causative factors for the discolouration. Inward migration of soaking water, containing some dissolved husk colour, as well as the husk splitting open, can also contribute to this discolouration. The intensity of the discolouration brought about in the parboiling process can be described as being proportional to the total heat treatment during the soaking and steaming process (Kimura *et al.*, 1976, 1983; Bhattacharya & Ali 1985; Bhattacharya, 1996; Lu & Lii, 1996;). Not only does soaking at too high temperatures have a negative influence on parboiled rice colour, similar discolouration can be obtained from steaming at too high pressures and drying at too high temperatures (Bhattacharya & Subba Rao, 1966b; Ali & Bhattacharya, 1982; Mohandoss & Pillaiyar, 1982; Velupillai & Verma, 1982; Chinnaswamy & Bhattacharya, 1986).

4. Quality grading of parboiled rice

Standards can be defined as a quantitative way of assessing certain quality characteristics. Grading can be described as the measured comparison of recognisable quality characteristics (IRRI, 2009). To date, there are few universally accepted international standards for both paddy and milled rice, because of the differences in paddy and milled rice quality. Countries that have a form of grading standards, include the Philippines, Thailand and the United States of America (USA). South Africa, as a net importer of all rice, including parboiled rice, did not have grading guidelines in place until very recently and had to rely on whatever grading the rice received upon shipment to South Africa. The new South African regulations, although still in draft format, are focused on the grading and packaging of rice (Anon., 2014). In the absence of rice regulations, in the past importers of the rice relied heavily on the grading standards of the country of origin and in many cases, these grading standards were also adopted.

Grading standards are variable, but generally the rice is evaluated on the same quality characteristics; for example, the Thai rice standards (Anon., 1997) look at grain classification, grain composition, and degree of milling and other matter present. Grain classification refers to the ratio of different grain lengths present in a sample. The CODEX standard for rice (Anon., 1995) indicates that if rice is classified as either being long grain, medium grain of short grain, this classification can be based on one of three classification options, namely kernel length/width ratio, kernel length, and a combination of kernel length and the length/width ratio (Table 1).

Table 1 Milled rice classification specification options (Anon., 1995).

	Kernel length/width ratio	Kernel length	Combination of kernel length (KL) and the length/width ratio (L/W)
Long grain	≥3.0	≥6.6 mm	KL: >6 mm L/W: 2- 3
Medium grain	2.0-2.9	6.2 - 6.6 mm	KL: 5.2 -6 mm L/W: <3
Short grain	≤1.9	≤6.2 mm	KL: 5.2 mm L/W: <2

Grain composition refers to the amount of whole and broken kernels present, as well as further classification of the broken grains into size (Refer to Table 2 for Thai composition and classification standards). Degree of milling gives an indication of how well the bran layer and germ have been removed from the rice grain during the milling process (de-husking, polishing, sorting and classification); this has a significant influence on aesthetic and nutritional value, as well as storage, packing and flow behaviours of the rice and hence is an important criterion in rice grading (Bhattacharya, 2011). Milled rice can be further classified according to degree of milling. Under milled rice is obtained by milling husked rice, but not to the degree necessary to meet the requirements of well-milled rice; well-milled rice is obtained by milling husked rice in such a way that some of the germ and all the external layers, and most of the internal layers of the bran have been removed. Extra-well-milled rice is obtained by milling husked rice in such a way that almost all of the germ and all the external layers, and the largest part of the internal layers of the bran, and some of the endosperm, have been removed (Anon.,1995). Lastly, foreign matter classification includes: under-milled kernels; yellow; black; partly black; peck kernels (whole or broken kernels of parboiled rice of which more than one quarter of the surface is dark brown or black in colour); damaged rice; glutinous rice; underdeveloped kernels; immature kernels; and other seeds and foreign matter (Anon., 1995).

It is important to note that the South African quality grading standards make little reference to the sensory attributes that should be considered in the grading process. The current draft regulations only state that a consignment of rice shall be free from abnormal flavours and odours, but these flavours and odours are not defined or described (Anon., 2014). The current standards are purely based on physical measurements of the grain sample being investigated.

Table 2 Thai standards for parboiled rice grain classification and grain composition (Anon., 1997).

Grades	Grain classification (%)				Grain composition		
	Long grain						
	Class 1 (≥ 7 mm)	Class 2 (>6.6 – 7 mm)	Class 3 (>6.2-6.6 mm)	Short grain	Whole kernels	Brokens	Small brokens
Parboiled rice: 100% sortexed	≥ 60		-	≤10	≥80	≤4	≤0.10

5. Analysis of parboiled rice eating quality

The sensory quality characteristics, mainly the eating quality of the parboiled rice, are greatly influenced by the processing conditions. Eating quality of rice can be defined as aroma, flavour, softness (hardness), cohesiveness (stickiness), whiteness and the gloss of the cooked rice (Juliano *et al*., 1965; Del Mundo, 1979).

Rice can be evaluated in terms of physical quality, cooking quality and eating quality; all of these have a role to play in consumer decisions on whether rice is deemed as being of good or poor overall quality.

Asian countries have reviewed criteria for evaluating the cooking and eating qualities of rice and included now are physicochemical properties, a cooking test, as well as properties of cooked rice (Juliano, 2001). Only properties influencing eating quality will be reviewed here.

5.1 Physicochemical properties

Physicochemical property measurement of rice is an indirect method of estimating eating quality based on, not only its chemical composition, but also on its gelatinisation properties (Kim & Rhee, 2004). The most important chemical constituents of rice, which are starch and protein, directly impact on eating quality. The amylose content is determined by the absorbance of the amylose-iodine complex (Fitzgerald *et al*., 2009) or by making use of the near infrared reflectance spectroscopy (NIRS) (Delwiche *et al*., 1996). For the determination of the protein content, the Kjeldahl method is the most preferred, but the NIRS has also been used (Kim *et al*., 2003). Another important physicochemical property is the degree of gelatinisation, which is measured by a differential scanning calorimeter (DSC) (Nakazawa *et al*., 1984; Shiotsubo & Takahashi, 1984; Wickramasinghe & Noda, 2008; Acquistucci *et al*., 2009; Wani *et al*., 2010).

5.2 Cooking tests

There are various cooking methods for rice; these have been classified into six groups: oven cooking method; cooking in a small amount of water; cooking in a medium amount of water; cooking in a large amount of water; steaming; and cooking in water or steaming with added oil (Batcher *et al*.,1963). The methods commonly used for evaluation of rice cooking tests are aroma and measurement of pasting viscosities, by either Rapid Visco Analyser (RVA) or Brabender viscoamylograph (Wickramasinghe & Noda, 2008; Tukomane & Varavinit, 2008; Lin *et al*., 2009).

Viscosity properties, measured on a Brabender viscoamylograph, are similar to those measured with the RVA (Blankeney *et al*., 1991). Since starch is one of the main components of rice, its gelatinisation properties are closely related to eating quality (Ohtsubo *et al*., 1998). Amylose content is inversely proportional to the degree of granule swelling during pasting (Lii *et al*., 1996; Sasaki & Matsuki, 1998). Amylose content (3.5-17.2%) of rice starch was significantly positively correlated with RVA peak viscosity, breakdown, set-back and pasting temperature (Noda *et al*., 2003). The paste breakdown of rice starches, with a fairly narrow range of amylose content (15.1-17.9%), but a wide variation in RVA pasting curve, was affected by the fine structure of amylopectin (Han & Hamaker, 2001). The proportion of long chains, which represents the long B chain of amylopectin, was negatively correlated with breakdown, while the proportion of short chains, which would be mostly A chains of amylopectin, was positively correlated with breakdown. Proteins in rice grain influenced RVA viscosity curves, both through binding water, which increased the concentration of the dispersed and viscous phase of gelatinised starch, and through the agency of a network linked by disulfide bonds (Martin & Fitzgerald, 2002).

5.3 Cooked rice properties

The properties of freshly cooked rice, that are important to consumers, include intact grains, appearance, gloss, softness, stickiness, taste and aroma (Juliano, 2001). These eating quality attributes are commonly evaluated by sensory testing, but instruments are also used to complement the sensory score (Ohtsubo *et al*., 1998; Champagne *et al*., 1999). Gloss of cooked rice is measured by a Midometer in Japan and Korea (Yoon, 2002).

Sensory attributes of cooked rice are usually measured by DSA (Champagne *et al*., 1998; Meullenet *et al*., 1998, 2000; Sesmat & Meullenet, 2001; Kim & Rhee, 2004; Lawless & Heymann, 2010). Descriptive sensory analysis is an objective tool used to characterise and analytically measure traits of aroma, flavour and texture of foods by a trained panel (Meilgaard *et al*., 2007). The technique has been used extensively for determining the effect of different growing and/or processing conditions on the sensory properties of rice (Meullenet *et al*., 1999, 2000; Champagne *et al*., 1997, 2004a, 2007, 2009). In order for the panel to be able to describe the food product characteristics, a lexicon needs to be created, as well as suitable reference standards, that describe the low and high intensity of any specific attribute. A lexicon is a set of words that describe the product characteristics (taste (flavour), aroma and texture) of a product or commodity (Drake & Civille, 2002).

5.3.1 Softness and stickiness

Texture is an important attribute of food acceptance by consumers (Moskowitz & Drake, 1972). Both DSA and instrumental tests are useful in the characterisation of cooked rice texture. The two approaches are usually explored simultaneously, in order to ascertain and evaluate correlations between the two methods (Szczesniak, 1968). A lexicon for rice texture was developed by Goodwin *et al*. (1996) and Lyon *et al.* (1999). The sensory texture profile include 13 sensory attributes that describe the rice texture at different phases of sensory evaluation. It starts off with the feel of the rice when it is first placed in the mouth and ends with the mouthfeel characteristics after the rice has been swallowed (Table 3). At present, one of the most popular and reliable instrumental methods for predicting cooked rice texture, involves the use of an Ottawa extrusion cell (Juliano *et al*., 1981, 1984; Meullenet *et al*., 1998)

Table 3 Descriptive analysis attributes and definitions used in cooked rice texture evaluation.

Attributes per phase[1]	**Definitions**
PHASE I	Place 6-7 grains of rice in the mouth behind the front teeth. Press the tongue over the surface and evaluate.
Initial starchy coating	Amount of paste-like thickness perceived on the product before mixing with saliva.
Slickness	Maximum ease of passing tongue over the rice surface when saliva starts to mix with sample.
Roughness	Amount of irregularities in the surface of the product.
Stickiness	Degree to which the kernels adhere to each other.
PHASE II	Place 2.5 mL of rice in mouth. Evaluate before or at first bite.
Springiness	Degree to which grains return to original shape after partial compression with molars.
Cohesiveness	Degree to which the grains deform rather than crumble, crack or break when biting with molars.
Hardness	Force required to bite through the sample with molars.
PHASE III	Evaluate during chewing.
Cohesiveness of mass	Maximum degree to which the sample holds together in a mass while chewing.
Chewiness	Amount of work to chew the sample.
Uniformity of bite	Uniformity of force throughout bites.
Moisture absorption	Amount of saliva absorbed by sample chewing.
PHASE IV	Evaluate after swallow.
Residual Loose Particles	Amount of particles in mouth
Toothpick	Amount of product adhering in/on the teeth

[1] Attributes intensities based on 0-15 scale.

5.3.2 Taste/Flavour

The flavour of rice has been studied by both instrumental and sensory methods. Many attempts have been made by researchers to assess rice flavour characteristics, primarily using DSA (Paule & Powers, 1989; Yau & Huang 1996; Yau & Liu, 1999; Suwansri *et al*., 2002; Champagne *et al*., 2004b). These studies, however, only featured a number of descriptive terms for characterising specific flavours or the range of flavour types was limited. Limpawattana and Shewfelt (2008) established a descriptive lexicon, with reference standards for describing the flavour properties of a board spectrum of rice; they also used the developed lexicon to characterise which sensory attributes are most important in rice flavour quality (Table 4). The rice types used for generating this lexicon was Jasmine, Basmati, Della, Sweet rice, Pigmented rice, Calrose, Kokuho, Long grain, Brown and Parboiled rice (Limpawattana & Shewfelt, 2008).

Table 4 Lexicon with reference standards for flavour attributes and descriptions of a board spectrum of rice.

Attributes	Definition	References[a]	Intensity
Popcorn	Aromatics reminiscent of popcorn	Orville Redenbacher's Gourmet popping corn	90
Starchy	Aromatics associated with the starch of a particular grain source	Bob's Red milled rice flour : water (1:1)	50
Woody	Aromatics associated with dry fresh cut wood	Toothpicks	50
Smoky	Aromatics associated with any type of smoke flavour	Colgin liquid smoking flavour	90
Cooked-grain	Aromatics associated with cooked grains	Nabisco cream of wheat	50
Grain	Aromatics associated with overall character impression of grain such as corns, wheat and oats	Grain mixture (rice flour, corn meal, white flour, and ground oatmeal (2:2:2:1)	40
Sulphur-like	Aromatics associated with sulphurous compound	Hard boiled egg	60
Corn	Aromatics reminiscent of canned yellow cream-style corn	Libby's cream-style corn	80
Nutty	Aromatics associated with roasted nuts	Planters roasted peanut	90
Floral	Aromatics associated with flowers	Twinings® Jasmine tea	50
Dairy	Aromatics reminiscent of pasteurized cow's milk	Great value 2% pasteurized milk	50
Hay-like	Aromatics associated with a dry, dusty, slightly brown aroma	Kaytee natural Timothy hay	80
Barny	Aromatics reminiscent of barnyard and stocks (manure, urine, moldy, hay, feed and so on)	Kroger white pepper	110
Buttery	Aromatics associated with natural fresh butter	Land O'Lake butter	55
Green	Aromatics (slightly sweet) associated with cut grass or green vegetable	Sunny creek organic alfalfa sprouts	80
Rancid	Aromatics associated with oxidized fats and oils	Canola oil aged 14 days at 80°C	60
Waxy	Aromatics associated with medium chain fatty acids	Candle wax	70
Earthy	Aromatics reminiscent of decaying vegetative matters and damp black soil	Sliced raw button mushrooms	50
Sweet-aromatics	Aromatics associated with sweet tastes	Bordeaux cookies Pepperridge Farm	65
Sweet	Basic taste sensation elicited by sugar	2% and 5 % sucrose solution	20, 50
Salty	Basic taste sensation elicited by salts	0.2% and 0.35% NaCl solution	20, 50
Bitter	Basic taste sensation elicited by caffeine	0.05% and 0.08% caffeine solution	20, 50
Astringent	Puckering or tingling sensation elicited by grape juice	Welch's grape juice	65
Metallic	Chemical feeling factor stimulated on the tongue and teeth by metal	Spring valley, 1 iron tablet/L	85

[a]Adapted from Civille & Lyon (1996), Goodwin *et al.* (1996), Meilgaard *et al,* (2007). Reference intensities were iteratively calculated as the mean rating of the group of 8 panellists using a 150 mm unstructured line scale where 0 = none and 150 = very high.

5.3.3 Aroma

To most people, rice is a rather bland food, but minor changes in sensory properties, especially aroma, can make rice unacceptable for the consumer (Yau & Liu, 1999). Many studies have been done on the volatile compounds of rice, and it was found that there is no single compound that can represent the aroma of cooked rice, but that it is rather a mixture of many aroma compounds (Yau & Liu, 1999). The aroma of cooked rice can either be evaluated by DSA or by making use of a gas chromatograph mass spectrometer (GC-MS) (Yau & Liu, 1999). Any sweet or mild aroma can be attributed to lactones being present, whilst 2-acetylthiazole contributes to the cereal-like aroma. Cooked brown rice samples have 41 odour-active compounds, of which 12 have high flavour dilution factors, i.e. low odour thresholds (Jezussek *et al*., 2002).

5.3.4 Colour

One of the most important attributes of raw and cooked rice is the degree of whiteness (Goodwin *et al*., 1992; Suwansri *et al*., 2002). Milled rice becomes darker and more yellow after parboiling. The degree of colour change during parboiling is affected by different factors, including soaking temperature and duration, steaming temperature and duration, and drying methods (Jayanarayanan, 1965; Johnson, 1965; Pillaiyar & Mohandoss, 1981; Elbert *et al*., 2001). The colour of rice can be evaluated by DSA or by making use of a colorimeter. In the latter, colour is reported as a tristimulus L*, a* and b*. The L* value makes reference to the black (0) to white value (100), the a* value indicates the green (-a*) to red value (+a*), and the b* value indicates the blue (-b*) to yellow value (+b*).

6. Summary

Rice is a diverse cereal grain, which is an important crop, as many people all over the world are dependent on it as their primary source of energy. Rice can exist in many forms, depending on how it is processed, and each format of rice has unique properties in terms of its physical, chemical and nutritional composition. South Africa is a net importer of rice, as no rice is locally produced and rice imports are increasing year on year.

Parboiled rice is the format of rice that is consumed the most by South Africans. It is produced by a process of soaking, steaming and drying of paddy rice, before it is milled into either brown parboiled or white parboiled rice. Parboiling alters the properties of rice significantly; especially the physicochemical, cooking and eating qualities are altered.

The most important chemical constituents present in rice are starch and protein, which impact directly on eating quality of rice. The eating quality of parboiled rice is greatly influenced by the processing conditions it is subjected to. Eating quality of rice can be defined as aroma, flavour, firmness, stickiness, whiteness, as well as the gloss of the cooked rice. These eating quality attributes are commonly evaluated by sensory testing, but instruments are also used.

Despite the importance of rice as a growing commodity in South Africa, draft regulations relating to rice have only recently been released. These regulations only make provision for the grading, packing and marking requirements for rice to be sold in South Africa, and little mention is made of any sensory qualities required of the rice. With very limited insight into this imported commodity and limited sensory guidance in terms of the rice regulations, the question arises of whether the parboiled rice currently imported and sold in South Africa is meeting consumer expectations and if processing improvements are required to increase sales.

To capitalise on the increase of rice consumption, importers and marketers of parboiled rice require a better understanding of the sensory properties that drive parboiled rice consumption, as well as a greater appreciation of the opinions, attitudes and perceptions of this segment of consumers. After thorough investigation it was concluded that no data are readily available specifically detailing the sensory profile and consumer preference of long-grain parboiled rice in South Africa.

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CHAPTER 3

SENSORY PROFILING OF LONG-GRAIN PARBOILED RICE (*Oryza sativa L.)*

Abstract

Twelve long-grain parboiled rice samples were collected from various rice-exporting countries, to capture, as much as possible potential variation in sensory characteristics. Descriptive sensory analysis was used to establish the full sensory profile of the long-grain parboiled rice samples and a lexicon, consisting of 26 attributes was developed, which includes descriptors for aroma, flavour, texture and appearance. The sensory quality of both uncooked (raw) and cooked long-grain parboiled rice samples (n = 12) was assessed. It was found that the sensory characteristics of long-grain parboiled rice was mostly described by appearance, texture and less so by aroma and flavour. Differences in sensory profiles between samples were evident, with the sample clustering in four different groups. One group clustered mainly on aroma and flavour, the next on appearance and the third on texture, while the last group had no distinct sensory attributes, that dominated this grouping.

1. Introduction

Rice consumption is on the increase in the main rice-producing countries, as well as in Southern Africa. South African rice imports are expected to increase to approximately 1 million tons in 2014. This is an increase of about 8%, from an estimated 925 000 tons in the previous year. High prices of rice-substituting crops, such as maize and wheat, are the main contributors leading to this increase (Anon., 2013).

Since South Africa entirely depends on rice imports to meet its domestic demand, the rice market is becoming more and more competitive, as many new importers and packers emerge. The bulk of the imported rice is made up of parboiled rice. With the increasing rice market, differentiation becomes challenging, yet it remains crucial. For this reason, it is critical that product attributes be well defined, described and quantified.

To remain competitive in the rice market, an understanding not only of consumers' preferences, but also of their expectations of a product is vitally important. It is difficult for the importer/seller of the rice to guarantee that consumer expectation will be met with every consignment imported, as they have little or no control over the manufacturing process. Consumer expectations need to be communicated to manufacturers, in terms of a sensory specification, so that product consistency can be achieved.

Until very recently, South Africa had no regulations relating to rice or rice quality (Anon., 2014); however, regulation in draft format has been published in 2014. The current draft regulation on rice focuses on the grading and packaging of rice, and little mention is made of the sensory quality of the end product, merely stating that "a consignment of rice shall be free from abnormal flavours and odours" (Anon., 2014). End-product flavours and odours are thus not defined, described or quantified in any way.

In view of the above-mentioned situation, this study was conducted to identify and quantify the sensory attributes associated with both raw (uncooked) and cooked rice, thereby creating a sensory profile for the product category of *long-grain parboiled rice*. By analysing the sensory characteristics of a broad range of long-grain parboiled rice samples, sourced from local imports and other international markets, it was possible to establish a sensory lexicon for long-grain parboiled rice, i.e. a list of sensory attributes, definitions and reference standards that could be used in industry, as a valuable quality control tool.

2. Materials and methods

2.1 Rice samples

Twelve long-grain parboiled rice samples were collected from various sources, i.e. international retail and trading agents, as well as the local South African retail market. Five samples were from South-East Asia, three from South America, two from India, and two from North America (n = 12) (Table1). These countries are regarded as the major exporters of rice. Approximately 15 kg of each sample was sourced and each sample consisted of randomly drawn and composited sub-samples obtained from a single batch (5 tons) of rice. In this study, *raw rice* refers to uncooked parboiled rice and *cooked rice* to cooked parboiled rice.

2.2 Descriptive sensory analysis (DSA)

Descriptive sensory analysis is an objective tool that can be used to effectively characterise and analytically measure traits of aroma, flavour and texture of foods, by a trained panel (Meilgaard *et al.*, 2007). The technique has been used extensively for determining the effect of different processing conditions on the sensory attributes of rice (Champagne *et al.*, 1997, 2004a, 2004b, 2007, 2009; Meullenet *et al.,* 1999, 2000).

Ten female judges participated in the study. The panellists were selected on their availability and interest. Most of the panellists had extensive experience with descriptive analysis of a wide range of commercial food products. None of the panellists had previous experience with sensory analysis of long-grain parboiled rice.

2.2.1 Sample preparation

Approximately 50 g of raw rice of each sample was placed in a Petri dish. The Petri dishes were enclosed to retain the aroma and prevent any contamination from the environment. Ten Petri dishes were prepared for each rice sample, one per panellist.

All rice samples were cooked in excess water, due to the fact that there is no agreed standard method for cooking rice (Bhattacharya, 2011). According to Bhattacharya (2011), any type of rice will absorb approximately 2.5 times its weight of water during the cooking process. It was therefore decided to use a ratio of 1 part rice to 6 parts boiling water for this study.

The cooking time for each rice sample was determined by the Desikachar and Subrahmanyan (1955) method, also referred to as the Ranghino test (1966). During the cooking process a few rice grains were removed at intervals and pressed between two glass slides. The time at which the opaque central core just disappears, is regarded as the final cooking time. Tap water (1.250 kg) was brought to the boil in saucepans on gas stoves, the rice (220 g) was added, the rice-water mixture was brought to the boil and the timer set, once the mixture started to boil (preliminary cooking times were established in a pilot study). Approximately 2 min before the cooking time was over, rice grains were evaluated, using the Ranghino test (1966). Once the rice was fully cooked, the saucepans were removed from the gas and the rice strained through a colander. Once the excess water was removed, the colander containing the rice was placed back into the saucepan and covered with the lid; the residual heat of the saucepan was utilised to maintain sample temperature. Before serving of samples commenced, the rice was stirred through once.

Prior to this study, it was decided that the rice temperature be representative of the temperature at which rice is generally consumed. Numerous measures were taken to keep the temperature of the rice as constant as possible. To achieve this, porcelain mugs, ¾ filled with boiling water, were placed into an industrial forced convection oven (Hobart CSD 1012, France) and pre-heated at 70°C until required. The mugs were then placed in scientific waterbaths (Scientific Manufacturing Company, Cape Town) set at 65°C. Approximately 40 g of each of the rice samples was dished out into the glass ramekins. Ten ramekins were prepared for each of the rice samples. The ramekins were placed on top of the porcelain mugs and covered with Petri dish lids to prevent temperature loss and loss of aroma.

2.2.2 Panel training

The training of the panel was conducted according to the consensus method, as described by Lawless and Heymann (2010). The panellists were given the background and objectives of the study, and received instructions on how to analyse the samples. They were asked to shake the Petri dish containing the raw rice, before evaluating the aroma. Thereafter they were instructed to evaluate the aroma, texture, flavour and appearance of the cooked rice samples. The panel was also requested to cleanse their palate between samples, using distilled water and unsalted, fat-free crackers.

During the first part of the training, panellists were exposed to a number of raw and cooked rice samples to become familiar with the product and the protocol of analysis. During eight one-hour sessions, all 12 samples were analysed and compared to one another, and the panel generated aroma, appearance, texture and flavour descriptors. Aroma was defined as the fragrance or odour perceived through orthonasal analysis, while flavour referred to the retronasal perception of aroma in the mouth. Texture can be defined as ‘‘the sensory and functional manifestation of the structural, mechanical and surface properties of foods detected through the senses of vision, hearing, touch and kinesthetics’’ (Szczesniak, 2001). Appearance can be defined as optical properties, including colour, physical form or shape and the mode of presentation (Hutchings, 1994).

Descriptive terms were suggested and deliberated in an open discussion, led by the panel leader, and each new term was recorded. Relationships and redundancies among the terms were discussed, and definitions for sensory descriptors were developed. The suitability of various reference standards was tested, to identify those that best described the specific sensory attributes. A control rice sample, both raw and cooked, was given to the panellists in each session. These control samples were consistently prepared from the same batch of rice throughout the sensory analysis period.

During the training sessions, the following attributes were finalised: seven raw rice aroma attributes and one raw appearance attribute; as well as seven cooked rice aroma attributes; four cooked texture attributes; four flavour; and three appearance attributes (Table 2 and 3). The final list of descriptors was regarded as relevant, unambiguous, non-redundant and non-hedonic. See Table 4 for the definitions of the respective attributes, including reference standards to illustrate the respective attributes. A score sheet was then developed, which showed each of the 26 descriptors, as well as the unstructured intensity scales, and was anchored on both sides with word descriptors (see Addendum 1 for questionnaire). During the final training sessions the panel practised the scoring of the individual attributes on the unstructured intensity scales. Maximum and minimum intensity values for the 26 descriptors were discussed and compared to the attribute intensity values that had been established for the control rice samples. The intensity of attributes that were not perceived in the control samples, was rated in relation to the samples with the highest intensity for that attribute.

2.2.3 Panel testing

After training had been completed, the panel was requested to use unstructured line scales to rate the intensities of the 26 attributes for each of the 12 rice samples, during three replicate sessions on three consecutive days. *Compusense five®* (Compusense, Guelph, Canada) was used as the data-capturing programme. The samples were presented to the panellists in two blocks, six samples at a time, making use of the partial present functionality. The panellists were requested to take a ten min break between the sessions to avoid panel fatigue. Samples were labelled with three-digit codes and presented to each panellist in a randomised order. The control sample was labelled in such a way that the panellists could easily identify it, and use it for comparison to the other samples. The average value of the control sample, for each attribute, was indicated on the line scale. All analyses were conducted in sensory booths fitted with *Compusense five®*, and temperature (21°C) and light were also controlled throughout the testing phase.

2.4 Statistical procedures

The data generated by all panellists for each sensory attribute, for every rice sample, was captured and analysed using various statistical techniques. Panel performance was monitored by making use of *PanelCheck* Software (Nofima Mat, Norway). Judge*Replication interaction and Judge*Sample interaction were used as measures to determine panel precision and homogeneity respectively, using SAS software (Version 9.2, SAS Institute, Cary, NC, USA). The Shapiro-Wilk test (1965) was used to test for non-normality ($p \leq 0.05$); outliers were identified and removed, until the data were normally distributed. Principal component analysis (PCA), using the correlation matrix, was conducted, using XLStat (Version 7.5.2, Addinsoft, France) to visualise and explain the relationships between the samples and their attributes.

3. Results and discussion

In this study 12 samples of long-grain parboiled rice, sourced from different countries, were tested sensorially for aroma (A), flavour (F), texture (T) and appearance attributes (Table 3). In some instances the samples were analysed in the raw (uncooked) state (R), in other instances in the cooked state (C). The main categories of attributes were thus aroma raw, aroma cooked, flavour cooked, texture cooked, and appearance, both raw and cooked.

3.1 Sensory attributes

The minimum, maximum and mean intensities depicted in Table 5 indicate that many sensory attributes scored below 10 on a 100-point scale. It was therefore decided to disregard these attributes as their intensities were barely perceptible and thus too low to base any conclusions on, i.e. in terms of the scope of this study. The majority of the disregarded attributes consisted of ten aroma attributes, three flavour attributes and two texture attributes. The 11 remaining attributes and their impact on quality will be discussed in more detail.

The prevalence of the attributes amongst the samples, plotted against their average intensity, is illustrated in Fig. 1. The following attributes were prevalent in a 100% of the samples at perceptible intensities (>10 on a 100-point scale): “whiteness intensity” of the cooked sample obtained the highest score, followed by “swollen/plump” appearance, “whiteness intensity” of the raw sample, “firmness”, “typical rice” aroma of the cooked sample, ”typical rice” flavour of the cooked sample, “springy/rubbery”, “typical rice aroma of the raw sample” and ”maize porridge” aroma of the cooked sample. From this it may be concluded that the sensory profile of the long-grain parboiled rice samples, used in this study, may be described as a combination of mainly appearance and texture attributes, with aroma and flavour contributing to a lesser degree. Tomlins *et al*. (2005) made use of a semi-trained sensory panel in their study, investigating consumer preference and sensory profile of locally produced and imported rice in West Africa. They discarded typical rice aroma, shape and size from further analysis, since they did not differ significantly between samples, and furthermore, PCA plots of the cooked and uncooked rice sensory attributes further showed that samples separated according to appearance (raw and cooked) and texture (cooked).

In contrast, in our study a sub-set of the samples illustrated specific aroma and flavour attributes at extremely low intensity levels, i.e. “buttery” flavour cooked (25% of samples), “hay” flavour in the cooked sample (42% of samples), “cardboard” flavour in the cooked sample (50% of samples) “sour” aroma in the cooked sample (67% of samples) and an “oily” aroma in the raw sample (92% of samples). Flavour attributes, common to this study and the research of Limpawattana and Shewfelt (2010), included “buttery”, “hay-like” and “cooked grain” flavours. Similarly, aroma attributes, corresponding to the research of Goodwin *et al*. (1996), included “grain” and “hay-like” aromas, while texture and appearance attributes were also found to correspond and include “hardness”, “grain-to-grain adhesiveness” and “tooth packing”.

3.2 Multivariate relationships between attributes and samples

Principal component analysis plots are frequently used in sensory analysis to illustrate the relationships between attributes and individual samples. A PCA model consists of principal components, with each component explaining a certain percentage of the variation. The first principal component (PC1) explains the largest percentage, followed by PC2, PC3, etc. Principle component models usually consist of two plots, i.e. a PCA scores plot, indicating how samples associate with one another, and a corresponding PCA loadings plot, indicating how the respective attributes associate. An example of a PCA loadings and scores bi-plot, with two principal components (PC1 and PC2), is illustrated in Fig. 2. Principle component 1 is in the direction of the horizontal axis and PC2 in the direction of the vertical axis. Scores (a-c) are indicated in red and loadings in black (u-z). Variables u and v have high positive loadings on PC1 and are positively associated. Variable w has a high positive loading on PC2 and is also positively associated to v and u due to the angle being smaller than 90°. The sharper the angle, the stronger the association will be between variables. Sample b associates strongly with variables u and v, i.e. it is closely associated to these variables. Variable x has a high positive loading on PC1 and is negatively associated with w, u and v due to the angle being larger than 90°. Both samples a and c are positively associated with each other and negatively associated with sample b. Sample a associates strongly with variable w and sample c with variable x. If the angle is 90° there is no association (Everitt, 1978). Variables y and z lie close to the origin, indicating they are not well explained by the principal components. Therefore not much can be concluded regarding these variables (Kjeldahl & Bro, 2010).

The PCA score plot (Fig. 3a) displays the association of the long-grain parboiled samples with one another and the PCA loadings plot (Fig. 3b), the association of the attributes with each other. Factor 1 (PC1) explained 29.89% of the variation, while Factor 2 (PC2) explained 16.05%. The PCA scores plot (Fig. 3a) clearly illustrates that certain samples grouped together, and four distinct clusters can be seen, indicated as Group 1, 2, 3 and 4, respectively. The PCA loadings plot indicates which attributes associate with which samples. The main attributes driving the association of the samples in Group 1 (WW and RiceL) are "buttery" flavour, "buttery" aroma, and "hay" aroma, i.e. all the cooked aroma and flavour rice attributes which were disregarded, because of their low intensities. In Group 2 (Indian, PY and Arroz) no sensory attributes dominated, except perhaps for some slight taints, such as "cardboard" aroma and flavour, which was also not perceptible due to its low intensity. Group 3 (Vietn, HDawn and Tasia) were dominated by several textural attributes in the cooked samples, especially "grain-to-grain stickiness", and "plump/swollen" appearance. Group 4 (AM, AC, Tastic and Spekko) were driven by two other textural attributes in the cooked samples, i.e. "firmness" and "springy/rubbery" texture.

Associations on the PCA loadings plot indicated that many attributes seem to be highly correlated. These correlations are, however, better understood by analysing their significant correlation coefficients ($p \leq 0.05$) in Table 6-8. Anticipated strong associations included that of "buttery" aroma and "buttery" flavour when cooked ($r = 0.804$), "whiteness intensity" of the raw and cooked samples ($r = 0.834$), "grain-to-grain stickiness" and "swollen, plump appearance" of the cooked samples ($r = 0.826$). The rest of the expected, significant ($p \leq 0.05$) correlations were all moderate, indicating that there was a large variation in product attributes amongst the 12 samples.

The significant ($p \leq 0.05$) differences in average attribute intensities between the samples are displayed in Fig. 4-7. For brevity, only the most prominent tendencies will be highlighted. For the attribute "typical rice" aroma (Fig. 4a), the mean score was 32.1 for all the raw samples. RiceL, WW and AC had intensity scores of >40, while Indian, PY and Tastic had scores of >30. In contrast, most of the cooked samples, except for AC and Tasia, illustrated similar and reasonably prominent intensities ($p > 0.05$) for "typical rice" aroma (Fig. 4c), i.e. more than 45 on the 100-point intensity scale. This indicates that the aroma note, "typical rice" aroma, is more noticeable in the cooked product.

The aroma attribute "crushed maize" (Fig. 4b) scored low in most of the raw rice samples, WW, PY, Tastic, AM, Tasia, AC and Vietn, which did not differ. Only the raw rice sample, Indian, scored significantly ($p \leq 0.05$) higher and was notable for "crushed maize" aroma. The attribute "maize porridge" aroma (Fig. 4d) increased in a number of the cooked rice samples, with Indian, as well as PY and AM, having means scores of >20. This aroma attribute was low and barely detectable in the rest of the cooked rice samples.

The "whiteness intensity" scored reasonably similar in both the raw and cooked samples (Fig. 5a and 5b), with the rice samples Vietn, Tasia, PY, Arroz and Indian scoring significantly ($p \leq 0.05$) higher for "whiteness intensity", than the rest of the samples. The latter cooked samples can all be regarded as white, since they all had mean scores ≥ 80 on a 100-point scale.

For the attribute "grain-to-grain stickiness" (Fig. 5c) of the cooked samples, Vietn showed the highest degree of "grain-to-grain stickiness", followed by Tasia and HDawn with a slightly lower degree of "grain-to-grain stickiness" than Vietn, but significantly ($p \leq 0.05$) more than the rest of the samples. The cooked samples Vietn, Tasia, HDawn and Indian illustrated a definite “swollen/plumpness” in appearance (Fig. 5d), significantly ($p \leq 0.05$) more so than the rest of the cooked samples.

The sensory attribute “typical rice” flavour was rather similar for all the cooked samples (Fig. 6), with Vietn having a mean score of 38 and WW a mean score of 47.7 for this attribute. This indicates that the cooked rice samples were very similar when analysed for this palate attribute; however, as indicated in Fig. 4, there were larger differences between samples when analysing the samples for the corresponding aroma attribute. The reason for this might be that there was no individual volatile compound that imparted a specific aroma to raw or cooked rice, but rather a combination of volatile components that contributed to the sensory perception. The proportions of these volatile components present in each sample would be different and would contribute to the differences between samples (Singh, 2000).

Texture is an important attribute when analysing cooked rice samples (Okabe, 1979; Rousset *et al*., 1999). The samples Spekko, AC, AM and Tastic scored high for the texture attributes “firmness” and “springiness” (Fig. 7a and b), significantly ($p \leq 0.05$) more so than all the other samples. Samples PY, RiceL, Arroz, Indian and WW were all moderately “firm” and “springy”, whereas Vietn, Tasia and HDawn were characterised as being the least “firm” and “springy” (Fig. 7.). As expected, the latter samples also illustrated the highest degree of “grain-to-grain stickiness” (Fig. 5). A study, investigating rice quality in the USA, found that rice that has a low amylose content and gelatinisation temperature, and is medium to short in length, tends have a higher grain-to-grain stickiness (Webb, 1985). In our study the two North American rice samples grouped together and had very similar profiles, while the other groups consisted of various countries’ rice samples. When considering reasons for the North American sample similarity, it was found that the US rice industry is very consistent in what it produces; the rice has been bred, selected and categorised into three standard grain types (long, medium and short) and each type has precise dimensional and cooking-processing features (Adair *et al*., 1973). The variability between the other groups can probably be explained by the fact that there are varietal differences, different agronomic practices were utilised, climatic conditions for growing were different, and lastly, that the processing of the rice (parboiling) was conducted differently.

3.3 Sample selection for consumer studies

The next step in the study was to make a decision on the samples to be used for further consumer analyses (see Chapter 5), where the aim was to get a better understanding of the sensory drivers of consumer preference for long-grain parboiled rice. It was decided that a total number of eight samples was the maximum number of samples, that could be presented to a consumer panel in one consumer testing session. In order to achieve this, the samples that were similar in terms of their overall sensory profile could be removed or, alternatively, the samples were based on what Pioneer Foods specifically wanted to retain or remove. The Indian, PY, Arroz and AC samples were the samples chosen not to be presented for the consumer study (Chapter 5). These samples were primarily very similar to other samples and had no unique attributes on which the consumer opinion was needed.

4. Conclusions

Our results showed that the primary sensory attributes of different samples of raw and cooked long-grain parboiled rice to characterise, but also to differentiate between, were *appearance* and *texture*. It was clear that aroma and flavour played a lesser role in this instance. The sensory attributes that differentiated the samples were “whiteness intensity” cooked, “swollen/plump” appearance cooked, “whiteness intensity” raw, “firmness” cooked, “typical rice” aroma cooked, “typical rice flavour” cooked, “springy/rubbery” cooked, “typical rice” aroma raw, “maize porridge” aroma cooked, “crushed maize kernel” aroma raw, “grain-to-grain stickiness”. Although most of the rice samples illustrated all the sensory attributes, the average intensity ratings for some of the attributes were very low (<10%), which implied that these attributes could be regarded as being below the normal detection point. It is recommended that future analysis continue with only the 11 selected attributes.

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Table 1 Long-grain parboiled samples used for sensory profiling.

Country of origin	Conventional name	Abbreviation/name used in this study
North America	Riceland	RiceL
	Woolworths	WW
India	Indian	Indian
	Harvest Dawn	HDawn
Vietnam	Vietnam	Vietn
Thailand	Tasia	Tasia
	Spekko	Spekko
	Tastic	Tastic
	Aunt Caroline	AC
South America	Americano	AM
	PY	PY
	Arroz	Arroz

Table 2 Aroma and appearance attributes for raw (uncooked) parboiled rice.

Aroma attributes	**Appearance attribute**
Typical rice	Whiteness Intensity
Cardboard	
Crushed maize kernel	
Raw oats	
Sour	
Stale/Dusty	
Oily	

Table 3 Aroma, texture, flavour and appearance attributes for cooked parboiled rice.

Aroma attributes	**Texture and appearance attributes**	**Flavour attributes**
Typical cooked rice	Firmness	Typical rice
Sour	Stickiness in mouth	Hay
Cooked maize porridge	Springy/rubbery	Cardboard
Toasted/Pot scrapings	Starchy after 5 chews	Buttery
Buttery	Whiteness Intensity	
Hay	Grain-to-grain stickiness	
Cardboard	Swollen/plump	

Table 4 Sensory lexicon describing aroma, flavour, texture and appearance characteristics of both raw and cooked long-grain parboiled rice.

Attributes		Definitions	Reference standards
Aroma of raw rice	A Typical rice R	Aromatics associated with rice cooking on a stove, when you lift up the lid from the saucepan	None supplied
	A Cardboard R	Wet cardboard aromatics	Cardboard soaked in a little water
	A Crushed maize kernel R	Crushed whole maize aromatics characteristic of chicken feed	Crushed whole maize kernel chicken feed
	A Raw oats R	Aromatics associated with raw oats	Raw oats
	A Sour R	Sour aromatics	None supplied
	A Stale/Dusty R	Closed, old closet aromatics	None supplied
	A Oily R	Aromatics associated with vegetable cooking oil, slighlty rancid note present	Conti Canola oil (aged)
Aroma of cooked rice	A Typical cooked rice C	Aromatics associated with rice cooking on a stove	None supplied
	A Sour C	Sour aromatics	None supplied
	A Maize porridge C	Aromatics associated with maize cooking on the stove, when you lift the lid from the saucepan	White Star cooked maize porridge
	A Toasted/Pot scraping C	Aromatics associated with maize porridge saucepanscrapings	White Star cooked maize porridge saucepan scrapings
	A Buttery C	Warm butter aromatics	None supplied
	A Hay C	Wet hay aromatics	Hay twigs soaked in a little water
	A Cardboard C	Wet cardboard aromatics	Cardboard soaked in a little water
Texture of cooked rice	T Firmness C	Degree of firm (hard) or soft	None supplied
	T Stickiness in mouth C	The amount of stickiness experienced in the inside of the mouth	None supplied
	T Springy / Rubbery texture C	Texture associated with the resistance to chew/ bite into the rice	None supplied
	T Starchy after 5 chews C	Starchy mouthfeel (floury) whilst/after chewing	None supplied
Appearance of raw and cooked rice	Whiteness intensity R	Degree of whiteness	None supplied
	Whiteness intensity C	Degree of whiteness	None supplied
	Grain-to-grain stickiness C	Visual adhesiveness of grains with one another	None supplied
	Swollen/Plump C	Degree to which grains are swollen/plump	None supplied
Flavour of cooked rice	F Typical rice C	Fundamental flavour sensation associated with cooked rice	None supplied
	F Hay C	Wet hay taste sensation	None supplied
	F Cardboard C	Cardboard-like taste sensation	None supplied
	F Buttery C	Warm butter flavour sensation	None supplied

The letters “A”, “R”, “F”, “C” and “T” refer to aroma, raw, flavour, cooked and texture, respectively.

Table 5 Minimum, maximum, mean and standard deviation values for the sensory attributes.

Variables	Minimum	Maximum	Mean	Standard deviation
A Typical rice R	18.389	50.056	32.182	7.732
A Cardboard R	0.000	3.333	0.687	0.873
A Crushed maize kernel R	0.000	23.389	10.845	5.380
A Raw oats R	0.000	15.611	5.499	4.805
A Sour R	0.000	11.167	2.830	3.387
A Stale/Dusty R	1.111	21.222	7.972	4.564
A Oily R	0.000	16.667	6.539	4.647
Whiteness Intensity R	49.444	75.056	60.963	6.962
A Typical cooked rice C	40.056	55.056	48.066	3.671
A Sour C	0.000	17.222	3.896	5.268
A Maize porridge C	7.278	29.444	16.889	5.625
A Toasted C	1.111	17.778	7.523	3.272
A Buttery C	1.111	15.000	6.079	3.186
A Hay C	0.000	17.333	4.168	4.397
A Cardboard C	0.000	0.000	0.000	0.000
T Firmness C	39.375	75.111	57.668	9.957
T Stickiness in mouth C	0.000	7.500	3.046	2.414
T Springy/Rubbery C	22.778	57.889	40.037	10.779
T Starchy after 5 chews C	0.000	16.722	6.245	3.845
F Typical rice C	34.444	49.611	42.083	4.241
F Hay C	0.000	5.000	1.022	1.392
F Cardboard C	0.000	2.833	0.526	0.831
F Buttery C	0.000	6.667	1.246	2.163
Whiteness Intensity C	65.611	88.944	77.526	7.082
Grain-to-grain stickiness C	1.722	43.571	14.017	10.730
Swollen/plump C	58.643	82.222	68.759	6.845

The letters “A”, “F”, “C”, ”T” and “R” in front or behind each attribute refer to aroma, flavour, cooked, texture and raw, respectively.

Table 6 Correlation matrix showing Pearson's correlation coefficients for sensory attributes.

Variables	A Crushed maize kernel R	A Raw oats R	A Sour R	A Stale/Dusty R	Whiteness intensity R	A Sour C	A Maize porridge C	T Springy/ Rubbery C	F Buttery C	Grain-to-grain stickiness C	Whiteness intensity C	F Hay C	A Typical rice R
A Crushed maize kernel R	1												
A Raw oats R	0.306	1											
A Sour R	**-0.463**	**-0.483**	1										
A Stale /Dusty R	**-0.354**	**-0.411**	**0.601**	1									
Whiteness intensity R	0.077	**-0.503**	-0.103	0.029	1								
A Sour C	-0.050	-0.113	0.159	0.134	0.099	1							
A Maize porridge C	0.272	-0.110	-0.167	**-0.378**	0.182	**-0.379**	1						
T Springy/Rubbery C	0.029	0.272	-0.052	**-0.443**	**-0.361**	0.325	-0.007	1					
F Buttery C	0.213	**0.600**	-0.271	-0.108	**-0.519**	-0.226	-0.312	-0.138	1				
Grain-to-grain stickiness C	-0.102	-0.213	0.111	**0.597**	0.288	-0.137	-0.217	**-0.805**	0.167	1			
Whiteness intensity C	-0.015	**-0.466**	-0.057	0.199	**0.834**	-0.098	0.075	**-0.640**	-0.281	**0.559**	1		
F Hay C	0.111	0.213	-0.155	-0.071	-0.229	**0.694**	**-0.439**	0.225	0.249	-0.092	-0.240	1	
A Typical rice R	**0.598**	**0.694**	**-0.454**	**-0.456**	**-0.453**	0.105	-0.022	**0.370**	**0.551**	-0.284	**-0.485**	**0.400**	1

All values in bold are significantly different from 0 with a 5% significance level. The letters "A", "F" and "T" before the attribute denote aroma, flavour and texture, whilst the "C" and "R" refers to the cooked or raw attribute, respectively. Correlation values denoted in pink are significantly different from 0 ($p < 0.05$), green are $r > 0.5$ and blue are $r < -0.5$.

Table 7 Correlation matrix showing Pearson's correlation coefficients for sensory attributes (cont.).

Variables	A cardboard R	A Oily R	A Typical rice C	A Toasted C	A Buttery C	A Hay C	A Card-board C	T Firmness C	Stickiness in mouth C	Starchy after 5 chews C	F Typical rice C	F Card-board C	Swollen/ plump C
A Cardboard R	1												
A Oily R	**-0.389**	1											
A Typical rice C	0.080	-0.028	1										
A Toasted C	-0.049	-0.223	0.193	1									
A Buttery C	-0.225	0.235	0.293	-0.214	1								
A Hay C	-0.254	0.147	0.051	-0.275	**0.739**	1							
T Firmness C	-0.267	**0.431**	-0.044	0.252	-0.044	0.025	-	1					
Stickiness in mouth C	0.315	-0.230	**-0.338**	-0.154	**-0.366**	-0.329	-	**-0.420**	1				
Starchy after 5 chews C	0.217	-0.286	-0.268	-0.031	**-0.441**	**-0.443**	-	**-0.403**	**0.785**	1			
F Typical rice C	-0.324	-0.031	0.228	-0.024	**0.432**	**0.397**	-	-0.054	**-0.587**	**-0.579**	1		
F Cardboard C	0.117	0.222	-0.029	-0.118	-0.095	-0.256	-	0.118	-0.209	0.027	-0.203	1	
Swollen/plump C	**0.342**	**-0.453**	-0.248	-0.192	-0.251	-0.263	-	**-0.776**	**0.620**	**0.584**	-0.104	-0.075	1

All values in bold are significantly different from 0 with a 5% significance level. The letters "A", "F" and "T" before the attribute denote aroma, flavour and texture, whilst the "C" and "R" refers to the cooked or raw attribute, respectively. Correlation values denoted in pink are significantly different from 0 ($p < 0.05$), green are $r > 0.5$ and blue are $r < -0.5$.

Table 8 Correlation matrix showing Pearson's correlation coefficients for sensory attributes (cont.).

Variables	A Cardboard R	A Oily R	A Typical rice C	A Toasted C	A Buttery C	A Hay C	T Firmness C	Stickiness in mouth C	Starchy after 5 chews C	F Typical rice C	F Cardboard C	Swollen/ plump C
A Crushed whole maize R	-0.260	0.282	-0.138	-0.148	**0.349**	**0.461**	0.082	-0.193	-0.319	0.194	0.162	-0.062
A Raw oats R	-0.327	**0.414**	0.032	-0.077	**0.577**	**0.619**	**0.331**	-0.166	**-0.406**	0.153	-0.285	**-0.445**
A Sour R	**0.660**	-0.292	0.031	-0.034	-0.302	-0.259	-0.124	0.169	0.223	-0.320	0.226	0.224
A Stale /Dusty R	**0.617**	**-0.574**	-0.077	-0.124	-0.294	-0.188	**-0.542**	**0.581**	**0.458**	-0.262	-0.169	**0.594**
Whiteness intensity R	0.027	-0.088	-0.154	-0.015	**-0.442**	**-0.432**	**-0.393**	0.264	**0.387**	-0.093	0.131	**0.521**
A Sour C	-0.106	0.053	**-0.511**	-0.216	**-0.439**	-0.108	0.246	0.259	0.272	**-0.417**	0.057	0.040
A Maize porridge C	-0.134	0.294	**0.366**	-0.007	-0.054	-0.212	0.101	-0.295	-0.243	0.183	0.293	-0.177
T Springy/Rubbery C	-0.187	0.326	-0.049	0.234	-0.142	-0.002	**0.926**	**-0.361**	-0.316	-0.154	0.132	**-0.761**
F Buttery C	-0.203	-0.018	0.111	-0.323	**0.804**	**0.824**	-0.126	-0.209	**-0.367**	**0.393**	-0.271	-0.190
Grain-to-grain stickiness C	**0.418**	**-0.460**	-0.00	**-0.357**	0.057	-0.044	**-0.835**	**0.579**	**0.469**	-0.051	-0.164	**0.826**
Whiteness intensity C	0.101	-0.307	-0.067	-0.051	-0.284	-0.274	**-0.677**	0.232	0.258	0.156	-0.065	-0.190
F Hay C	**-0.346**	0.084	**-0.486**	-0.103	-0.024	0.285	0.246	0.078	0.072	-0.073	-0.212	-0.059
A Typical rice R	**-0.383**	**0.418**	-0.026	-0.210	**0.521**	**0.678**	**0.428**	**-0.364**	**-0.488**	0.313	-0.010	**-0.468**

All values in bold are significantly different from 0 with a 5% significance level. The letters "A", "F" and "T" before the attribute denote aroma, flavour and texture, whilst the "C" and "R" refers to the cooked or raw attribute, respectively. Correlation values denoted in pink are significantly different from 0 ($p < 0.05$), green are $r > 0.5$ and blue are $r < -0.5$.

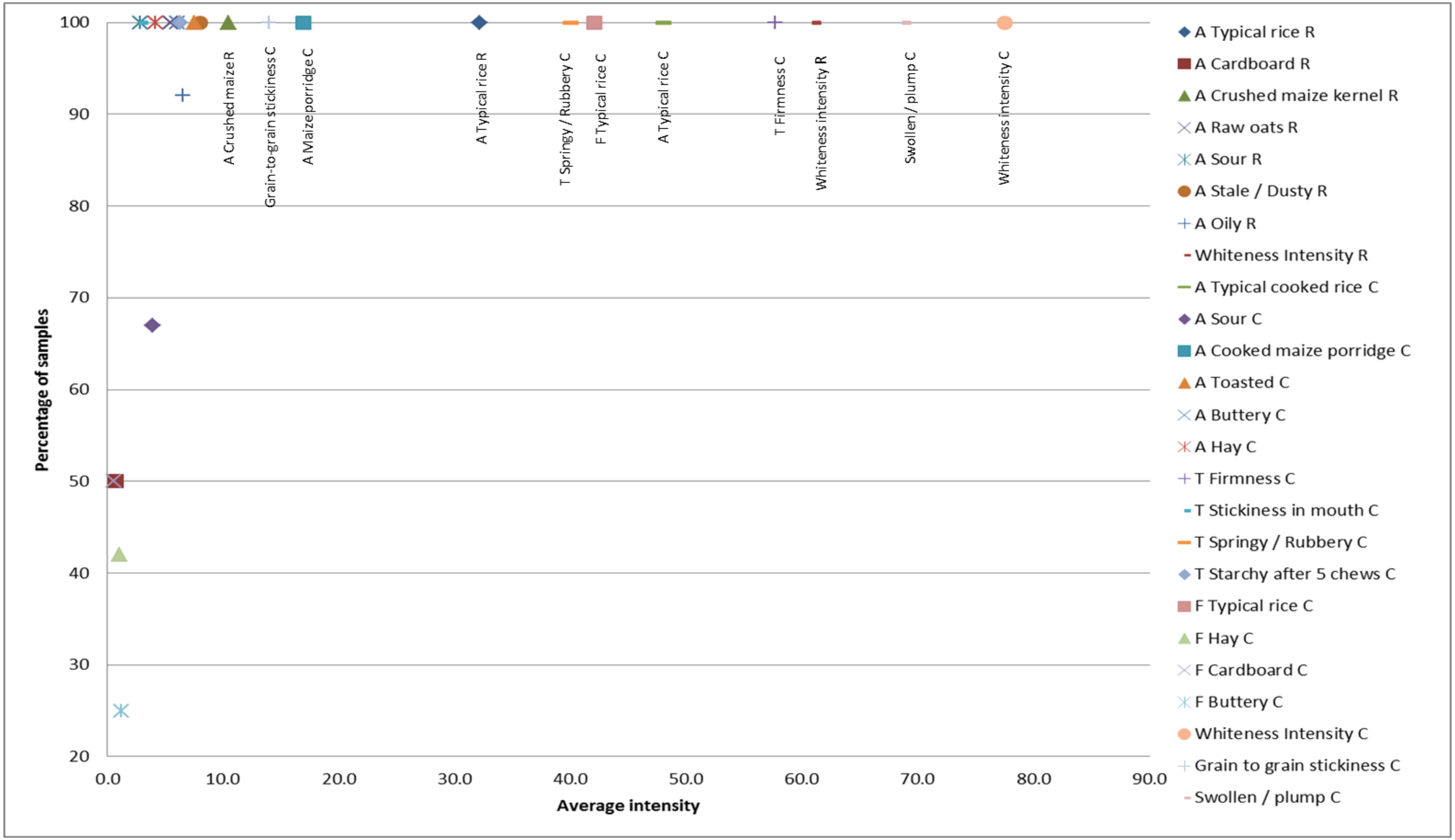


Fig. 1 Scatter plot indicating the percentage of samples that exhibit a certain attribute vs. the average intensity of that specific attribute. The letters “A”, “F”, “C”, “T” and ”R” in front or behind of each term refer to aroma, flavour, cooked, texture and raw, respectively.

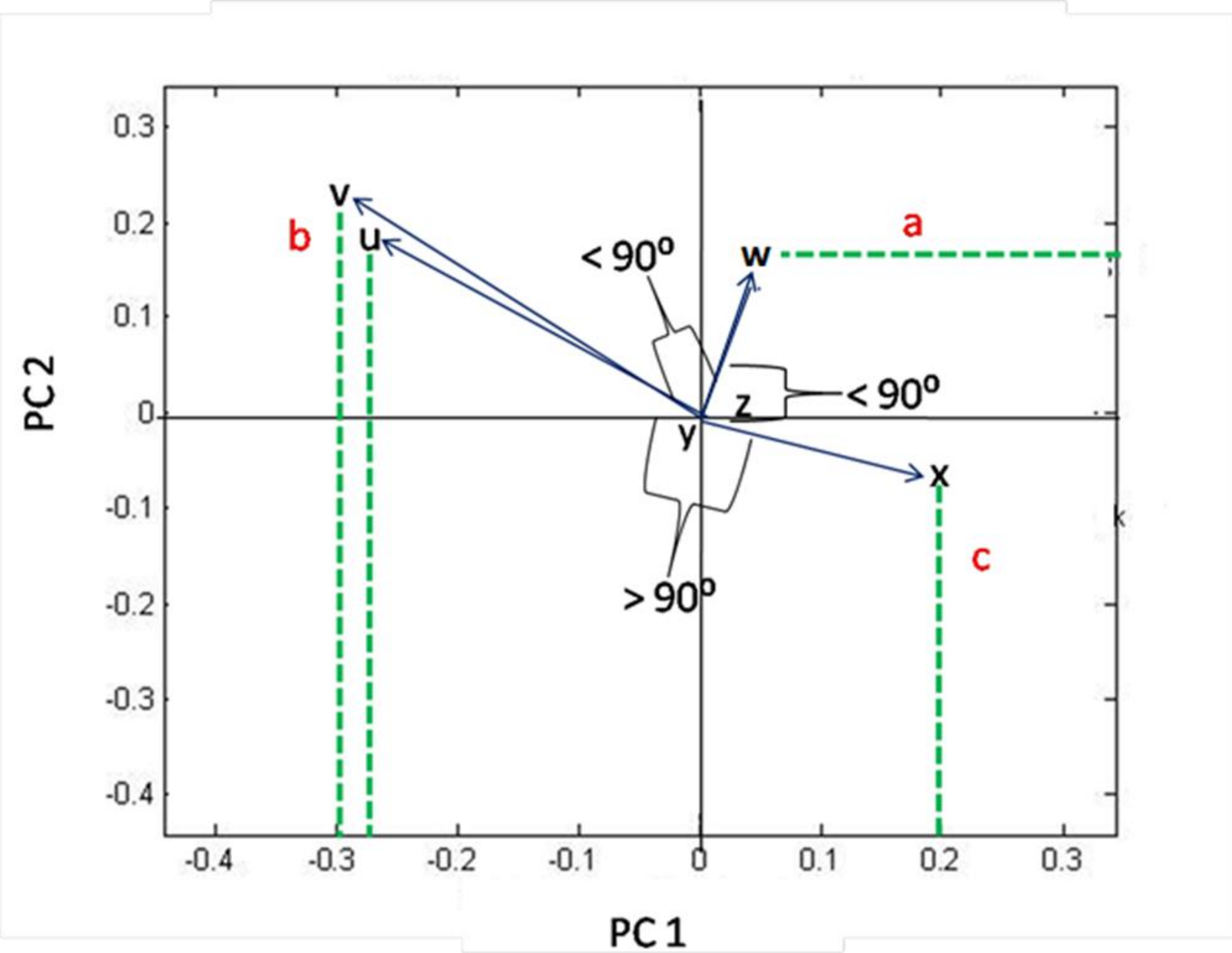
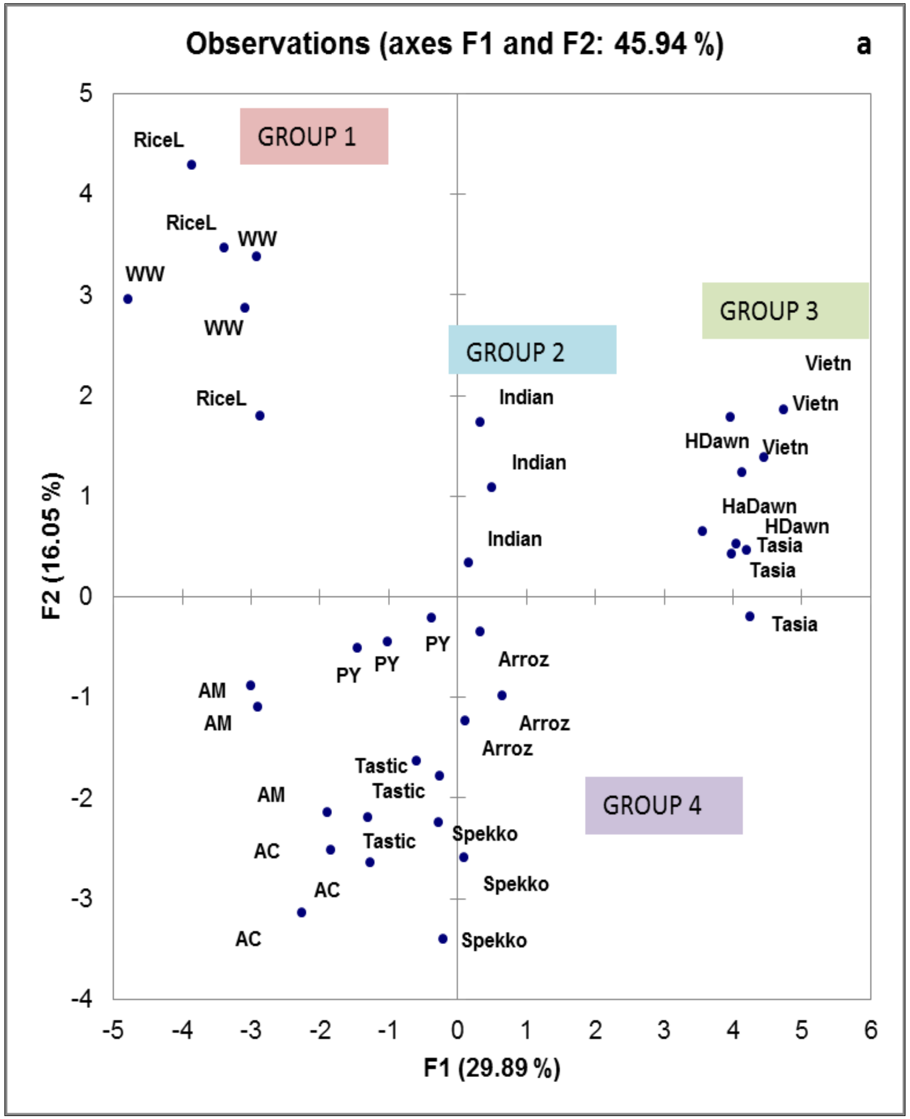


Fig. 2 Example of a PCA scores and loadings plot (bi-plot). Scores indicated in red and variables (attributes) in black. Green lines indicate loadings on relevant principal components. Black brackets indicate angles.



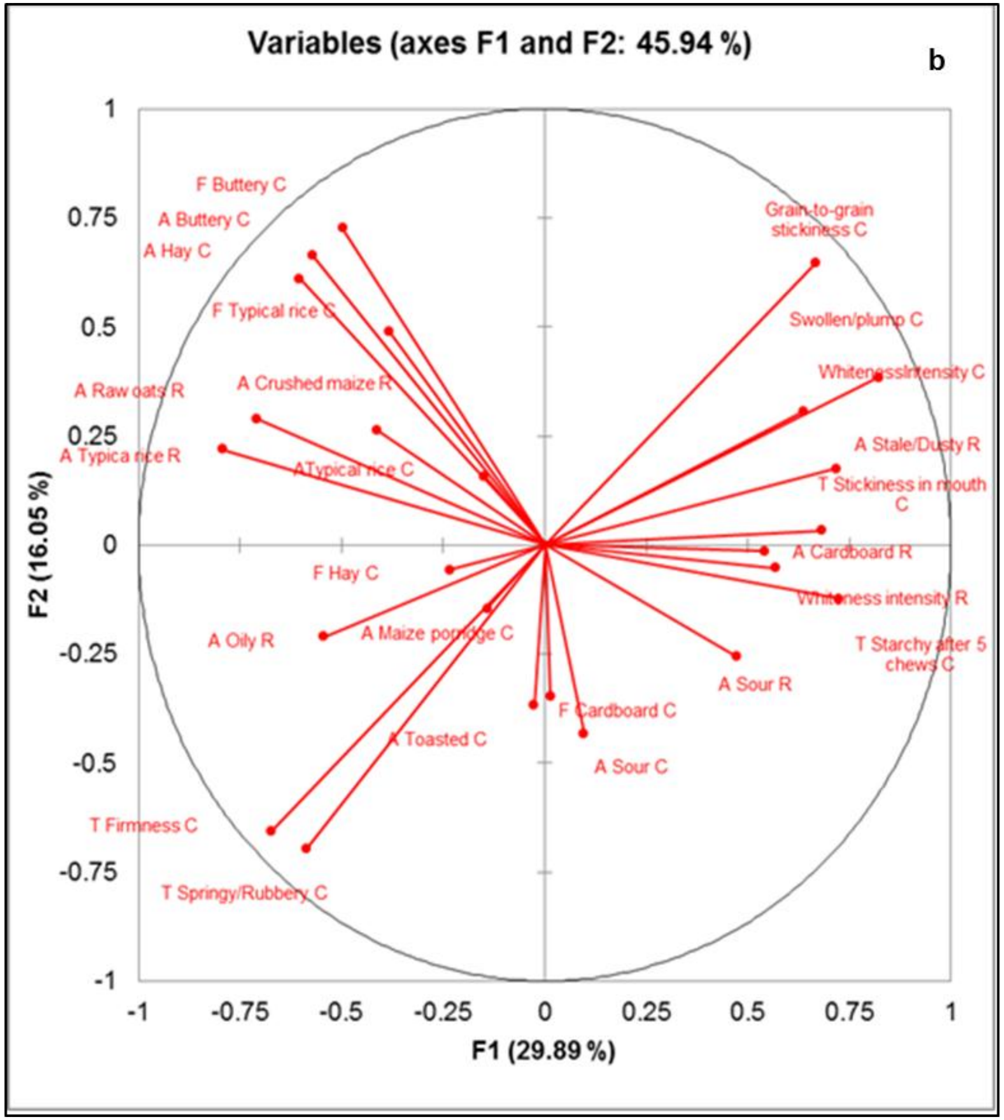
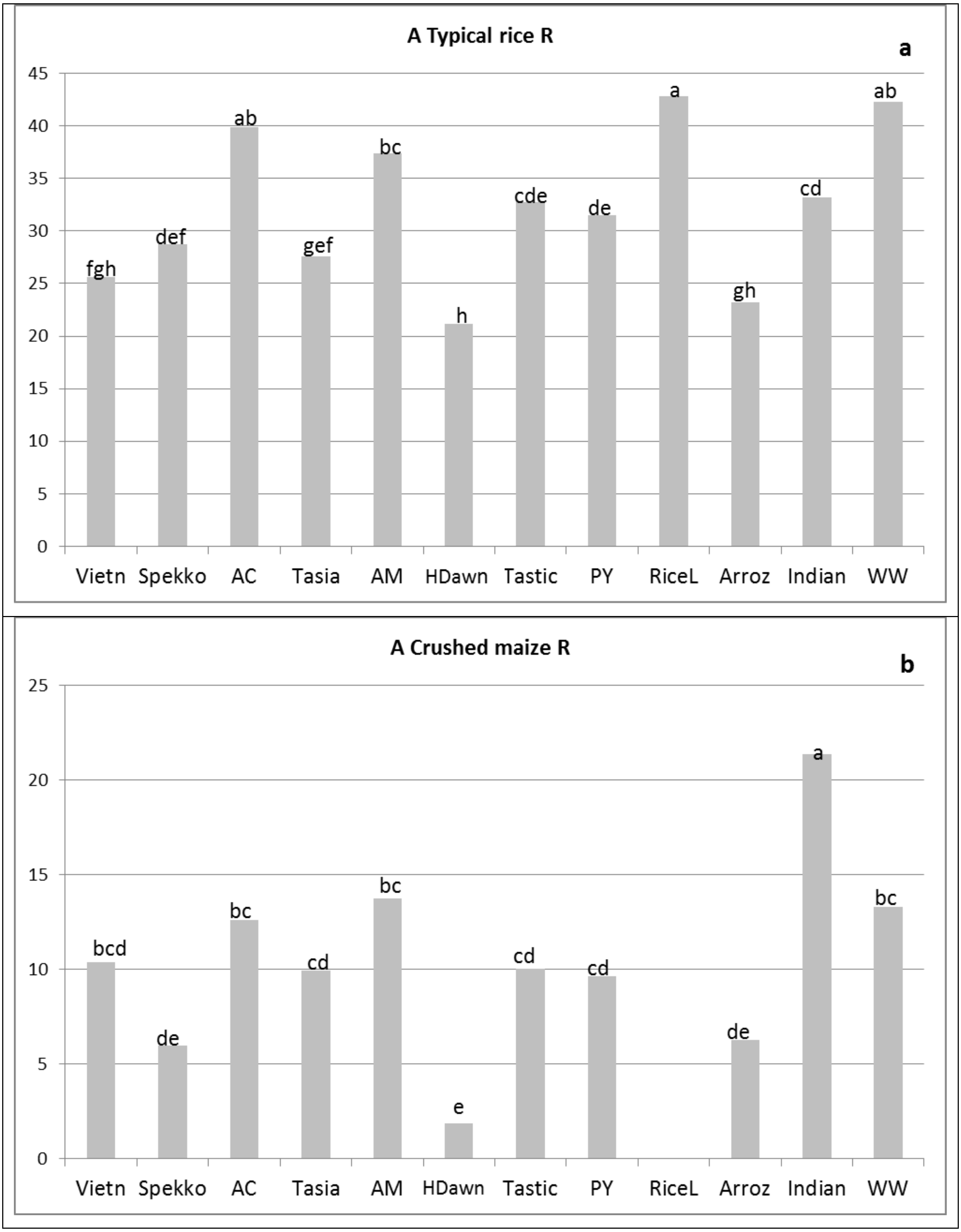


Fig. 3 PCA scores **a)** and loadings, **b)** plots showing the positioning of the 12 long-grain parboiled rice samples and the 26 sensory attributes, respectively. The DSA was replicated three times, resulting in three mean scores per rice variant.


A Typical rice R
a
45
40
35
30
25
20
15
10
5
0
fgh
def
ab
gef
bc
h
cde
de
a
gh
cd
ab
Vietn
Spekko
AC
Tasia
AM
HDawn
Tastic
PY
RiceL
Arroz
Indian
WW
A Crushed maize R
b
25
20
15
10
5
0
bcd
de
bc
cd
bc
e
cd
cd
de
a
bc
Vietn
Spekko
AC
Tasia
AM
HDawn
Tastic
PY
RiceL
Arroz
Indian
WW

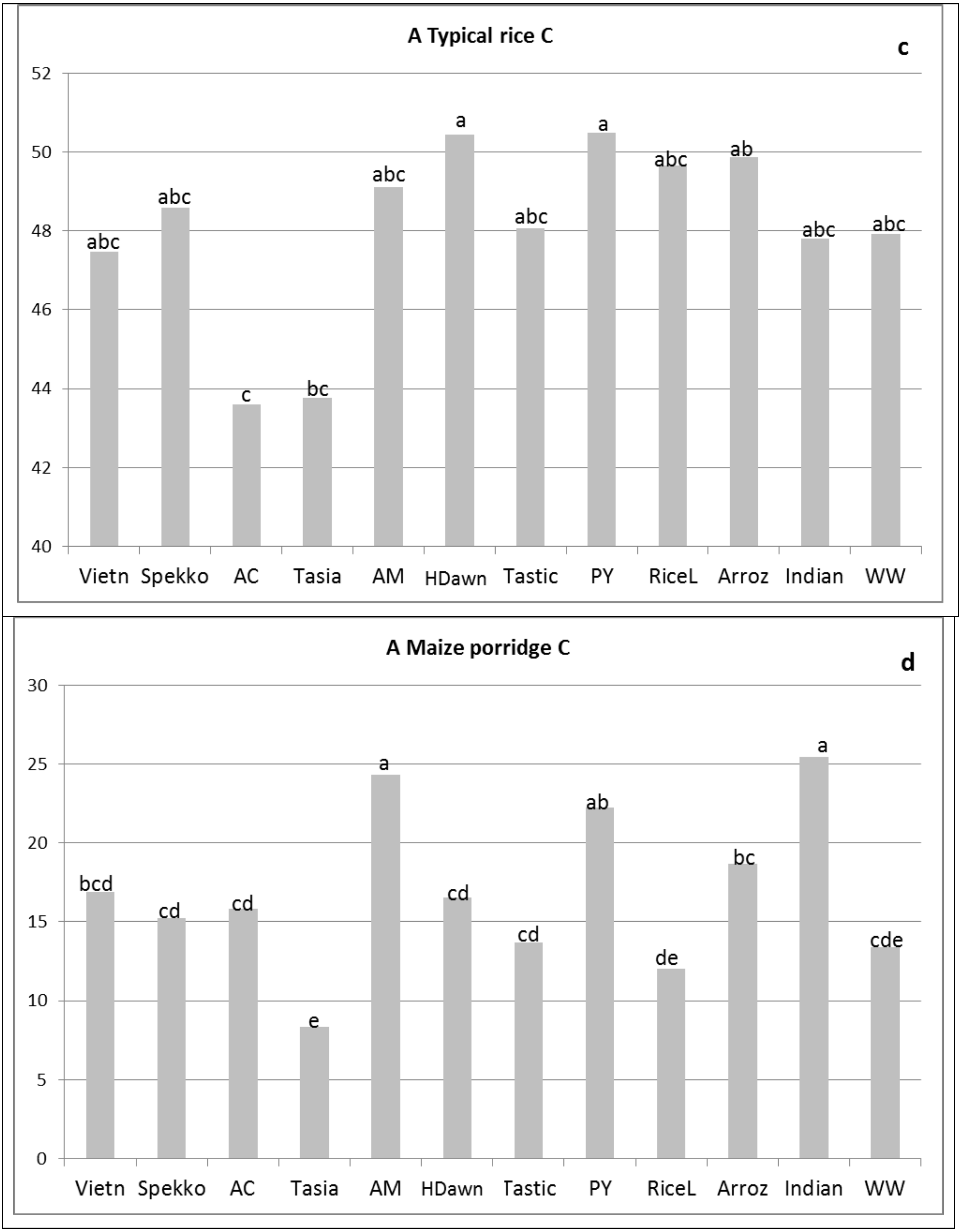
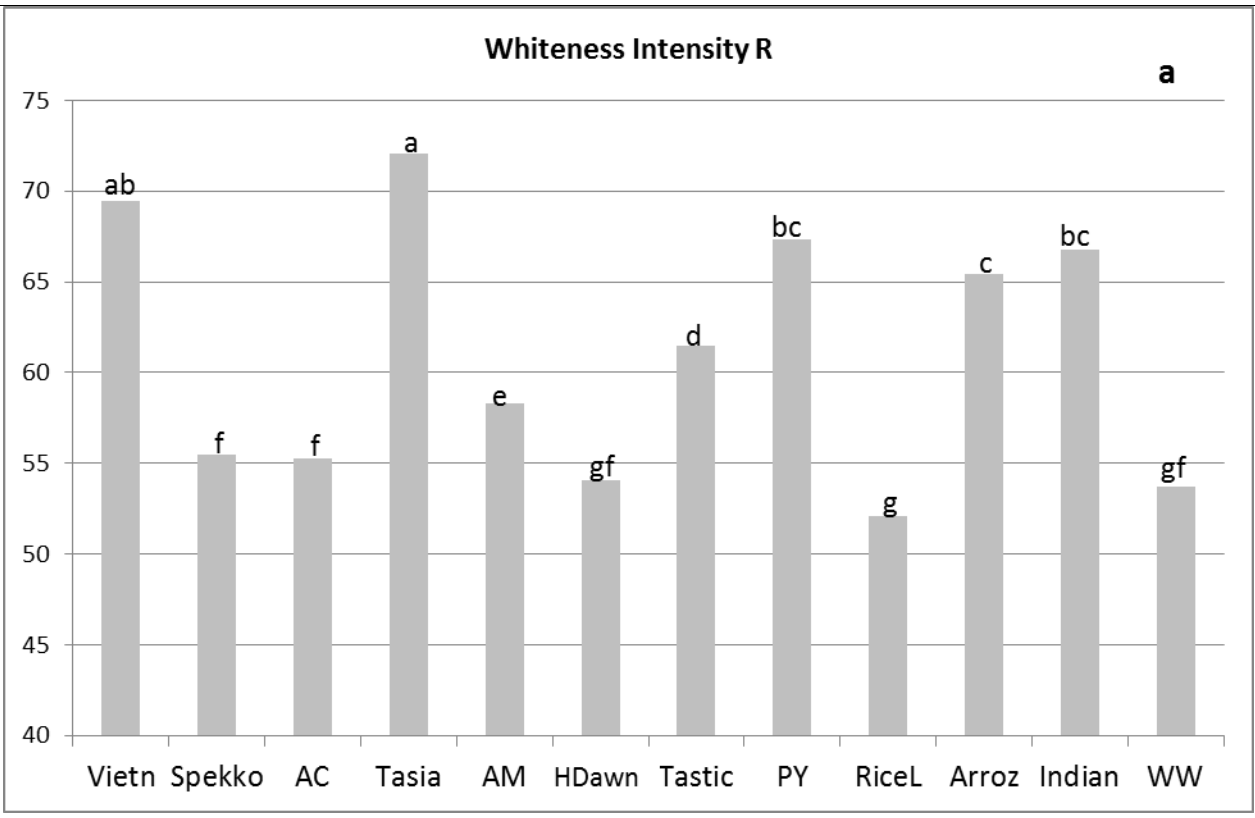
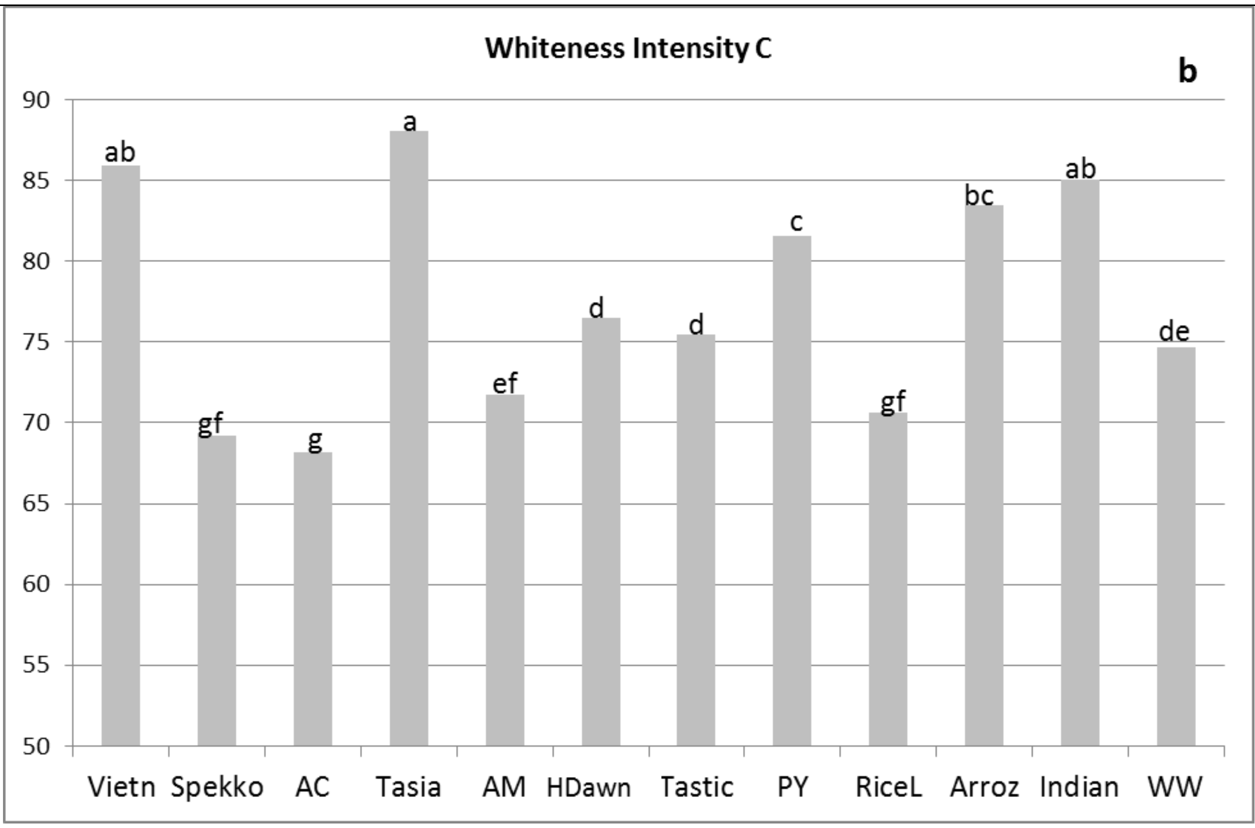


Fig. 4 Mean intensity scores for the aroma attributes **a)** "Typical rice" aroma raw, **b)** "Crushed maize" aroma raw, **c)** "Typical rice" aroma cooked, **d)** "Maize porridge" aroma cooked of the respective rice samples. Bars with different alphabetical letters are significantly different from one another ($p \leq 0.05$). The letters "A", "R" and "C", respectively, refer to aroma, raw and cooked.


Whiteness Intensity R
a
75
70
65
60
55
50
45
40
ab
f
f
a
e
gf
d
bc
g
c
bc
gf
Vietn Spekko AC Tasia AM HDawn Tastic PY RiceL Arroz Indian WW


Whiteness Intensity C
b
90
85
80
75
70
65
60
55
50
ab
gf
g
a
ef
d
d
c
gf
bc
ab
de
Vietn Spekko AC Tasia AM HDawn Tastic PY RiceL Arroz Indian WW

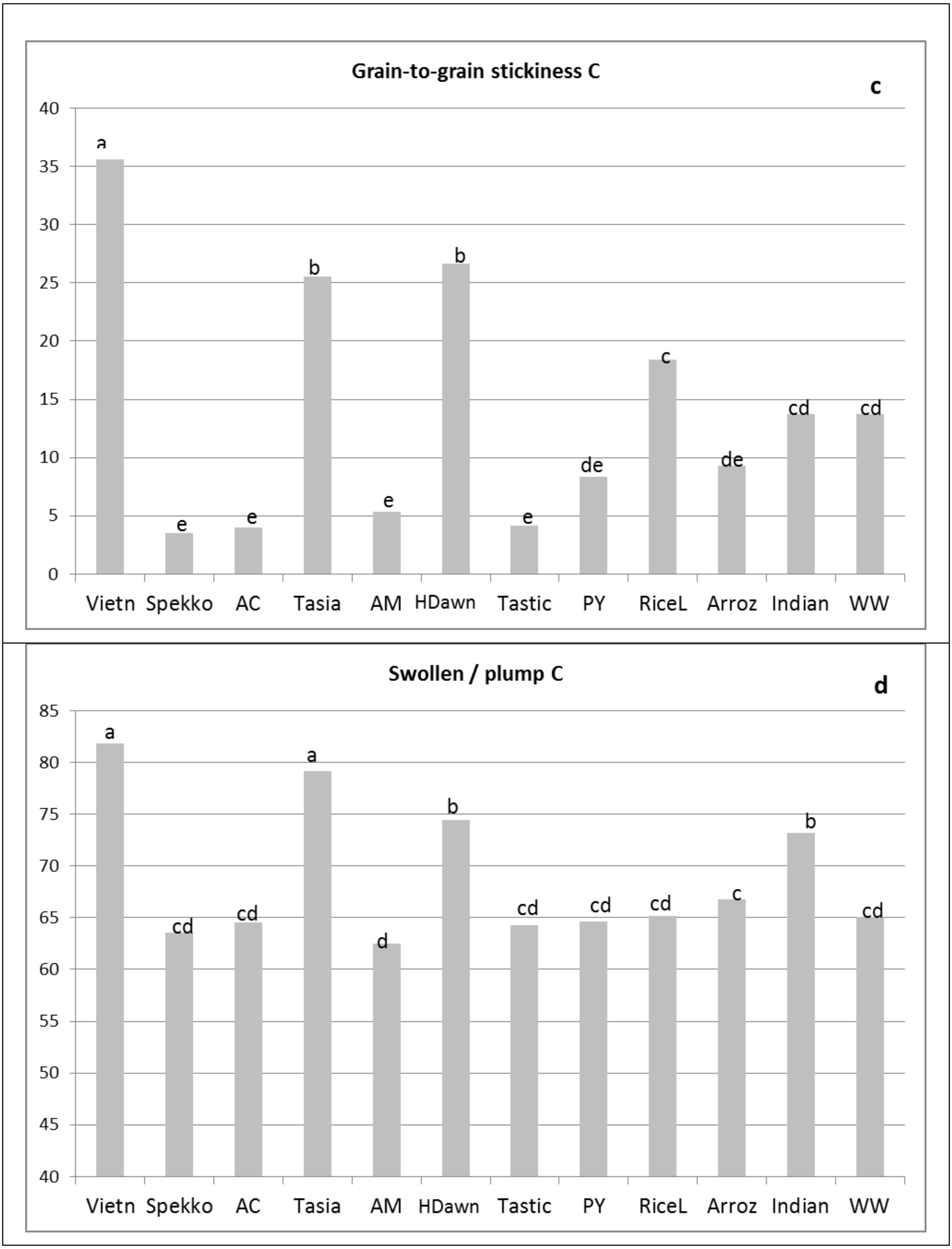


Fig. 5 Mean intensity scores for the appearance attributes **a)** "Whiteness intensity" raw, **b)** "Whiteness intensity" cooked, **c)** "Grain-to-grain stickiness" cooked, **d)** "Swollen/plump" cooked of the respective rice samples. Bars with different alphabetical letters are significantly different from one another (p≤0.05). The letters "R" and "C", respectively, refer to aroma, raw and cooked.

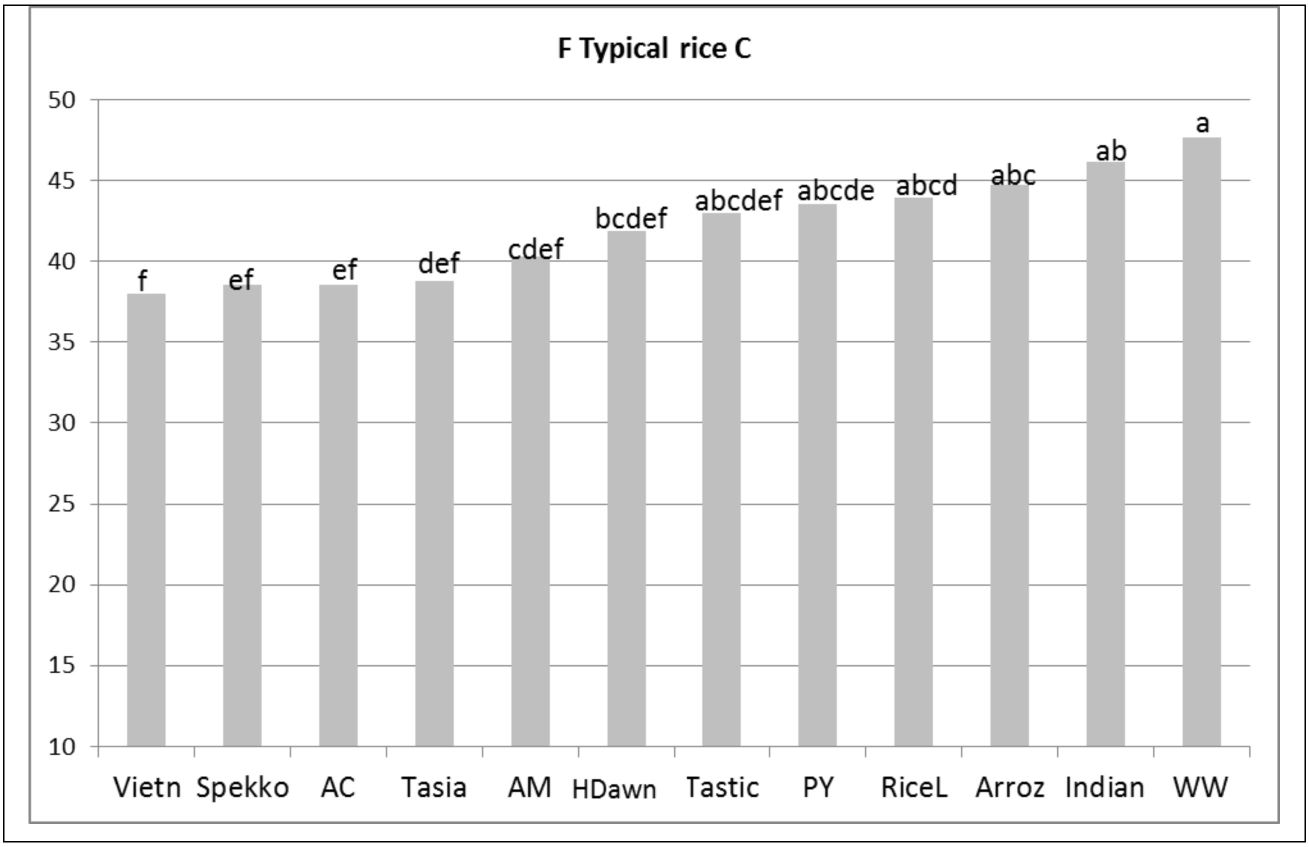


Fig. 6 Mean intensity scores for “Typical rice” flavour of the respective rice samples. Bars with different alphabetical letters are significantly different from one another ($p \leq 0.05$). The letters “F”, and “C”, respectively, refer to flavour and cooked.

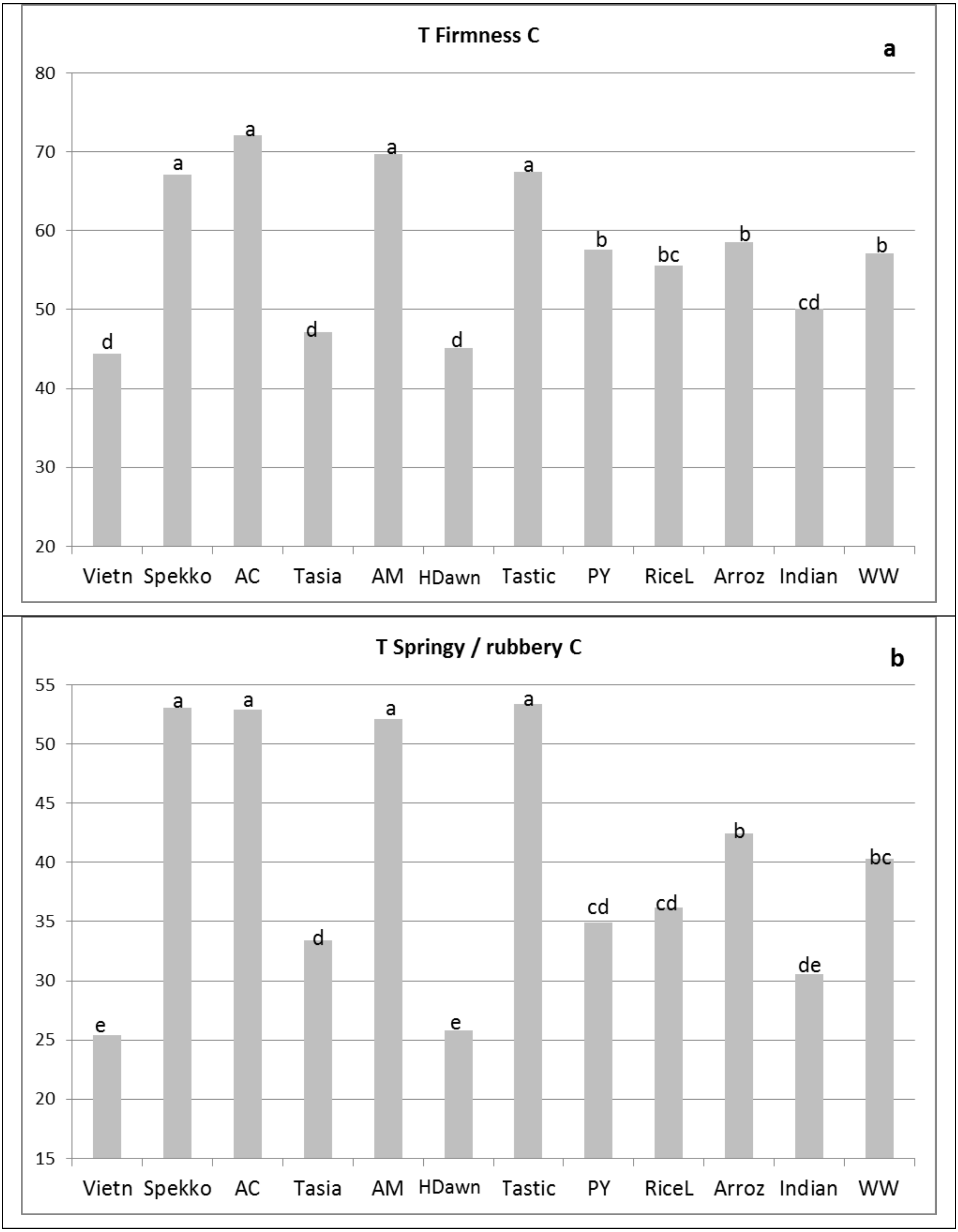


Fig. 7 Mean intensity scores for the textural attributes **a)** "Firmness", **b)** "Springy/rubbery" of the respective rice samples. Bars with different alphabetical letters are significantly different from one another ($p \leq 0.05$). The letters "T" and "C", respectively, refer to texture and cooked.

Addendum 1 – Questionnaire for trained DSA panel

Sensory Analysis: Parboiled Rice		Training 4: Tuesday 19 July 2013											
RAW RICE: Tray 1													
Attribute	**Description**	**F**	**H**	**D**	**L**	**E**	**J**	**A**	**B**	**G**	**K**	**C**	**I**
Aroma and Appearance	**Shake the petri dish and evaluate the sample**												
Typical rice aroma	0 = no aroma; 100 = prominent rice aroma												
Wet cardboard aroma	0 = no aroma; 100 = prominent wet cardboard aroma												
Crushed whole maize kernel aroma	0 = no aroma; 100 = prominent crushed maize aroma												
Raw oats aroma	0 = no aroma; 100 = prominent raw oats aroma												
Sour aroma	0 = no aroma; 100 = prominent sour aroma												
Stale / Dusty aroma	0 = no aroma; 100 = prominent stale / dusty aroma												
Oily aroma	0 = no aroma; 100 = prominent oily aroma												
Whiteness Intensity	0 = not white / yellow; 100 = pure white												

Sensory Analysis: Parboiled Rice			Training 4: Friday 18 July 2013											
PREPARED RICE: Tray 1			**F**	**H**	**D**	**L**	**E**	**J**	**A**	**B**	**G**	**K**	**C**	**I**
Aroma	**Remove covering from dish and sniff sample**	**REF**												
Typical cooked rice aroma	0 = none; 100 = prominent	60												
Sour	0 = none; 100 = prominent	0												
Cooked maize porridge	0 = none; 100 = prominent	40												
Toasted aroma/popcorn	0 = none; 100 = prominent	10												
Buttery	0 = none; 100 = prominent	10												
Hay-like	0 = none; 100 = prominent	0												
Cardboard-like	0 = none; 100 = prominent	0												
Texture	**Use a clean spoon to taste the samples**													
Firmness	0 = soft; 100 = hard / firm	50												
Stickiness in mouth	0 = loose; 100 = sticky	0												
Springy, rubbery texture	0 = not springy, 100 = springy / rubbery	20												
Starchy after 5 chews	0 = not starchy; 100 = very starchy	0												
Flavour	**Use a clean spoon to taste the samples**													
Typical rice flavour intensity	0 = none; 100 = prominent	40												
Hay / wet plant material	0 = not hay like; 100 = high hay-like flavour	0												
Cardboard flavour	0 = no cardboard; 100 = high cardboard	0												
Buttery flavour	0 = no butter; 100 = very buttery	0												
Appearance	**Do not stir, evaluate surface appearance**													
Whiteness Intensity	0 = off white; 100 = pure white	90												
Grain to grain stickiness	0 = loose; 100 = very sticky	20												
Swollen / plump appearance	0 = not plump; 100 = very plump	80												

CHAPTER 4

COMPARISON OF DESCRIPTIVE SENSORY ANALYSIS AND THE SORTING TASK AS TEST TECHNIQUES FOR PROFILING LONG-GRAIN PARBOILED RICE

Abstract

The sorting task has been developed as a rapid method of profiling food products, as an alternative to descriptive sensory analysis (DSA). In this study, 12 long-grain parboiled rice samples were subjected to both DSA and sorting analysis, to ascertain whether sorting can be used as an alternative method for profiling long-grain parboiled rice, especially within an industry research and development environment. Sorting, with a descriptive step, was conducted with trained judges and two industry experts, and the data obtained during the sorting task were analysed, making use of three statistical multivariate data-analysis techniques, namely multidimensional scaling (MDS), DISTATIS and correspondence analysis (CA). The latter results, in the form of graphical representations, were compared to establish whether samples with similar sample attributes grouped together. Similarly, the sorting plots were also compared to the principal component analysis (PCA) bi-plots derived from descriptive sensory analysis, primarily to investigate if the same product groupings were evident between the respective types of plots. RV coefficients, which are measures used to determine the similarity between two product configurations, were also calculated. It was found that sorting can be used as a rapid method of broad-based profiling of long-grain parboiled rice, as an alternative to DSA, for the following attributes: raw and cooked appearance; cooked texture; and cooked aroma and flavour. Profiling of raw rice aroma by means of sorting, however, did not produce favourable results in comparison to DSA.

1. Introduction

In a competitive market it is of critical importance for the food industry to know the full sensory profile, associated with their range of food products (Cartier *et al*., 2006). In order to achieve this objective, descriptive sensory analysis (DSA) is usually conducted to specify the nature and intensity of the sensory characteristics perceived in a product (Stone & Sidel, 2004; Lawless & Heymann, 2010). In many industries DSA is regarded as standard methodology to achieve the latter aim, primarily because it has proven to provide detailed, comprehensive sensory information and valid results (Rodrigue *et al*., 2000). Large DSA datasets can be analysed, using multivariate techniques such as principal component analysis (PCA). This efficient data-analysis tool “simplifies and describes the interrelationships among multiple dependent variables”; it furthermore illustrates the association of variables (descriptors) and objects (products). Principle component analysis transforms the original data into a new set of variables called principal components (Lawless & Heymann, 2010).

That being said, DSA has a few disadvantages. This sensory analysis method forces the panellists to divide their perceptions into independent sensory dimensions. The validity of this approach may be challenged, as it does not reveal the same information on complex perceptions or the interactions between sensory attributes, as the more broad-based, holistic approaches (Lawless, 1999; Saint-Eve *et al.*, 2004). Descriptive sensory analysis is a consensus method which involves intensive training of an analyst panel, making use of reference standards to ensure that all members of the panel are in agreement on the meaning of each sensory attribute analysed (Popper & Heymann, 1996; Campo *et al*., 2010; Lawless & Heymann, 2010). As a result of this, DSA can be very time consuming and expensive, and many industries cannot afford to make use of this type of technique when research and development time is limited, or when a broader, holistic view of the sensory profile is required (Stone & Sidel, 2004; Meilgaard *et al*., 2006; Kemp *et al*., 2009).

The sorting task has been developed as a rapid method of profiling food products, as an alternative to DSA. Various papers have compared the sorting task with conventional sensory profiling (Tang & Heymann, 1999; Saint-Eve *et al*., 2004; Soufflet *et al*., 2004; Faye *et al*., 2004, 2006; Cartier *et al*., 2006; Blancher *et al*., 2007; Lelièvre *et al*., 2008, 2009). The sorting task is a quick, easy-to-perform method for collecting similarity data (Healy & Miller, 1970; Coxon, 1999). The sorting task requires the assessor to sort together products based on their perceived sensorial similarity (Abdi *et al*., 2007). The assessors can either be trained or untrained. The training for a rapid technique, such as sorting, is very similar to that of DSA and involves the development of a lexicon with reference samples, allowing an alignment and standardisation of the sensory concepts within the group of assessors (Ishii & O'Mahony, 1990; Chollet *et al*., 2011). During the sorting task, the assessors are placed in front of a set of products and are instructed to compose different groups of products, based on the products' similarities. Each of the formed groups should be coherent and homogenous in terms of global sensory profile (Chollet *et al*., 2011). The sorting task can be stopped at this point or a description step can take place, where assessors are required to describe each group of products (Lawless, *et al.*, 1995; Tang & Heymann, 1999, Saint-Eve *et al*., 2004; Lim & Lawless, 2005; Cartier *et al*., 2006; Faye *et al*., 2006; Blancher *et al*., 2007; Lelièvre *et al*., 2008, 2009; Santosa *et al.*, 2010).

The data obtained during the sorting task can be analysed by making use of several statistical methodologies. These techniques include multidimensional scaling (MDS), DISTATIS and correspondence analysis (CA). Multidimensional scaling is a multivariate data analysis technique that analyses the similarity relationships, to produce a map of the stimuli (Abdi *et al*., 2007). In this map the similarities between the stimuli are represented by points which are positioned in such a way, that the distances between any two points reflect the similarities between the pair of stimuli. Two stimuli, which have often been sorted together, will be close on this representation map, while two stimuli which have rarely been sorted together, will be far apart (Abdi *et al*., 2007). The representation on a map might give insight into the dimensions, underlying stimulus similarities and differences. Correlations with additional attributes of the stimuli are often used in the interpretation of the MDS dimensions (Kruskal & Wish, 1978; Schiffman *et al*., 1981). One of the major problems with MDS is that information on participants is lost, because the individual data are pooled to be able to obtain the similarity matrix; this means that individual differences are hidden and the average representation may bear little resemblance to each of the individual assessor's representations. There is no way to evaluate the agreement among assessors or to visualise the repeatability of the individual assessors, when repetitions are done (Abdi *et al*., 2007).

In order to overcome this limitation of MDS, DISTATIS was developed (Abdi *et al*., 2005; Abdi & Valentin, 2007a). This method combines MDS (Togerson, 1958; Kruskal, 1977; Borg & Groenen, 2000; Abdi, 2007a) and STATIS (Escoufier, 1980; Lavit, 1988; Schlich, 1996, Abdi & Valentin, 2007b) and takes individual assessor data into account. When analysing data obtained from sorting with DISTATIS, two types of maps are generated: a product map; and an assessor map. The proximity between two points on such a map denotes their similarity and, hence, these maps can be interpreted by using the same rules when interpreting MDS and PCA plots. The product map is generated by analysing the between-product matrix. In this matrix all the assessors' distance matrices are combined, while the assessors map is generated by analysing the similarity between the distance matrices, representing the assessors' sorting actions (Abdi *et al*., 2007).

Correspondence analysis (Greenacre, 1984; Lebart *et al*., 1984) is another graphical multivariate data-analysis tool which can be used to investigate the symmetric association between category (row and column) variables (McEwan & Schlich, 1991; Beh *et al*., 2011). The rows represent the products and the columns the attributes used to describe the products (McEwan & Schlich, 1991). The plots generated through CA indicate the overall correlation structure between products and the sensory attributes associated with them (Beh *et al*., 2011).

Although it has been indicated that DSA is the preferred option when comprehensive information about sensory attributes of a product is needed (Delarue & Sieffermann, 2004; Saint-Eve *et al*., 2004; Lelièvre *et al*., 2008; Perrin *et al*., 2008), the sorting task can be used to rapidly position a product among others on a perceptual plot, using similarities and differences (Campo *et al*., 2010). In view of this, the objective of this study was to determine the extent to which conventional DSA can be substituted by the sorting, task for the profiling of long-grain parboiled rice.

2. Material and methods

In this study two basic sensory analysis methodologies were compared, i.e. the traditional profiling method, DSA, and sorting, a rapid profiling technique. The methodology and results of the DSA method are described in Chapter 3.

2.1 Rice samples

Twelve long-grain parboiled rice samples were sourced for conducting DSA, as well as the sorting task. Refer to Table 1 for the list of samples, as well as their countries of origin.

2.2 Sample preparation

See Chapter 3 for details regarding sample size and sample preparation. The same sample preparation procedures were used for both profiling methodologies.

2.3 Descriptive sensory analysis

Refer to Chapter 3 for the details regarding the training of the sensory panel, as well as executing of the standard profiling method, DSA.

2.4 Design and procedure for the sorting task

2.4.1 Panel for the sorting task

The panel used during the sorting task consisted of 12 judges. Ten of these judges were trained and participated in the DSA of the long-grain parboiled rice samples (Chapter 3), the other two judges were untrained, but were regarded as rice experts from industry.

2.4.2 Testing procedures

The sorting was scheduled to take place over two sessions on two consecutive days. During the first session (Day 1), the judges were firstly asked to sort the samples on raw aroma and appearance, and after that, on cooked rice aroma and flavour. Both sets of samples were coded differently and presented in a random order. During the second session (Day 2), the judges were asked to sort the samples on cooked appearance, as well as cooked texture. Again these samples were coded and presented in a completely random order to the judges.

During each sorting session the panel of twelve judges had to sort the 12 long-grain parboiled rice samples relative to one another and in not more than six groups, according to their similarities. The panel of judges was allowed to assess each rice sample as many times as they liked. The only restriction was that each group of samples must appear homogenous and that no sample could be placed into two groups. After that the judges had to describe each group of samples, with one to five sensory attributes. The glossary of sensory terms used in the DSA (Chapter 3) was at their disposal, but they were also free to use their own terms. In addition to describing each grouping of samples with sensory terms, the panel was also instructed to indicate if the groups contained “high”, “low” or “zero” levels of the mentioned attributes. Refer to the Addendum 2 for an example of instruction sheet for the sorting task, as well as the descriptive step for “cooked rice” aroma and flavour. Similar instructions and score sheets were used for the other groups of attributes. Only one replication of the sorting task was conducted.

2.5 Statistical procedures

2.5.1 Analysis of DSA data

Refer to Chapter 3 for the statistical analysis of DSA data.

2.5.2 Analysis of sorting data

Once the sorting task was completed, the panel had to assign descriptive terms most suited to each group of samples. Since the panel was not limited to the terms of the DSA glossary, the full, composite list of terms, used by the panel for the respective sorting tasks, had to be streamlined, to include only terms that are regarded as non-redundant, meaning that the sensory terms should not overlap or have similar meanings. A final list of nine descriptors for raw appearance, ten descriptors for raw aroma, eight descriptors for cooked and raw appearance, ten descriptors for texture, and ten descriptors for cooked aroma and flavour were used, as input to generate the various plots. It is evident from Table 2, that similar descriptors were used to denote both raw and cooked appearance, as well as cooked texture.

Each judge’s data were captured on an indicator matrix, where a row represents a rice sample and a column represents a grouping of rice samples. A value of “1” indicates that a specific rice sample represented by row was sorted into a specific grouping of samples, represented by column. Similarly a “0” was used to indicate that a rice sample was not sorted in a specific grouping of samples (Abdi *et al*., 2007). Following this, the data were further pre-processed into co-occurrence matrices, distance matrices and, lastly, into cross-product matrices as described by Abdi *et al*. (2007).

Three different data-analysis methods were used to analyse the data generated during the sorting task, namely multidimensional scaling (MDS), DISTATIS and correspondence analysis (CA). RV coefficients were used as a theoretical tool to statistically compare the various multivariate techniques utilised (Abdi, 2007). All analyses were conducted using Statistica 12 software (Statsoft, Inc., Tulsa, Oklahoma, USA).

3. Results and discussion

3.1 Evaluation of sorting as rapid profiling technique

The graphical representation of the three different statistical techniques, used to analyse the sorting data, will be discussed below. The discussion is based on the various classes of characteristics evaluated: raw aroma; raw appearance; cooked appearance; cooked texture; and cooked aroma and flavour.

The reason for including two industry experts as part of the panel, was to see how the results of the industry experts compared to those of trained DSA judges, and whether any differences in product grouping or descriptors were evident. According to Cartier *et al*. (2006), similar sorting results were obtained by making use of either trained or expert judges; however, when using expert industry judges in our study, it was evident that the trained DSA judges were more consistent in grouping similar samples together.

The various sorting plots, illustrating the grouping of the long-grain parboiled rice samples based on *raw aroma,* are shown in Fig. 1a-c. Four clear groupings were evident on the MDS plot (Fig. 1a) and DISTATIS plot (Fig. 1b). In the CA plot (Fig. 1c), it can be seen that there was no clear separation of samples, with the exception of Spekko, HDawn and Vietn, which all lay on their own in different positions of the CA plot. Most samples associated well with the majority of the descriptors, with the exception of “sour”, “stale/dusty”, and “bland aroma”, which associated strongly with Spekko, Vietn and HDawn, respectively.

The sorting plots depicting the grouping of the long-grain parboiled rice samples based on *raw appearance* are shown in Fig. 2a-c. The MDS plot (Fig. 2a), as well as the DISTATIS plot (Fig. 2b) clearly illustrated four similar sample groupings. Although the CA plot (Fig. 2c) showed reasonably similar groupings to the MDS and DISTATIS plots, the CA plot clearly separated the rice samples into two distinct groups: the samples on the left of the CA plot were higher in “whiteness intensity”, while the rice samples on the right were lower in “whiteness intensity”, thus more yellow in colour. Since six of the nine descriptors illustrated in this CA plot are colour-related descriptors, the deduction can be made that colour played a pivotal role when sorting raw rice samples into groups. Other descriptors which were considered during grouping were “kernel size” and “blemishes”,that may be present on the rice kernels (Fig. 2c).

The respective sorting plots, illustrating the grouping of the long-grain parboiled rice samples based on *cooked appearance,* are shown in Fig. 3a-c. The MDS plot illustrated four clear sample groupings (Fig. 3a), while the DISTATIS plot depicted five sample clusters (Fig. 3b); however, the samples on the left and right sides of both the MDS and DISTATIS plots were similar. The CA plot clearly differentiated between the samples in terms of both “whiteness intensity” and texture-like descriptors. In the CA plot (Fig. 3c) it can be seen that there were three groupings of samples; the samples to the left are “off-white” in colour and the grains are “loose”, i.e. no degree of “stickiness”; the samples midway are described as “slightly sticky”, whereas the samples on the right side of the plot are described high in “whiteness intensity” and “plump” and “sticky” in texture.

The sorting plots showing the grouping of the long-grain parboiled rice samples based on *cooked texture* are shown in Fig. 4a-c. Both MDS and DISTATIS plots indicated three reasonably similar sample groupings (Fig. 4a and b). The CA plot (Fig. 4c) for cooked rice texture indicated separation of the rice samples based on their characteristics to be either “loose, dry, rubbery” and “firm” or “soft” and “sticky”.

The sorting plots showing the grouping of the long-grain parboiled rice samples, based on *cooked rice aroma and flavour,* are shown in Fig. 5a-c. The MDS plot illustrated three distinct groups, with Spekko indicated as a slight outlying sample (Fig. 5a). In the DISTATIS plot (Fig. 5b) the groupings were reasonably similar to those of the MDS plot; however, in this instance the rice sample Spekko definitely forms part of the grouping in the bottom left corner of the DISTATIS plot. The CA plot for cooked rice aroma and flavour indicated a separation of rice samples based on three aroma descriptors (Fig. 5c). One group of samples associated with “typical rice aroma and flavour”, “toasted aroma”, “cooked maize aroma”, and “cooked maize porridge”. Two other groups were evident, one with a more “hay-like aroma” and “buttery flavour”, and another with a “sour aroma”.

3.2 Comparison of sorting and DSA as profiling methodologies

The question arises whether the profiling results, acquired through extensive DSA of long-grain parboiled rice, will be comparable to those obtained when conducting rapid techniques, such as sorting. By comparing the PCA bi-plots (DSA results) with the MDS, DISTATIS and the CA plots (sorting results), this question could be answered, especially when considering the fact that the industry does not always have the means and time to conduct extensive DSA (Rodrigue *et al*., 2000).

In order to compare the DSA results (PCA plots) with those generated during sorting (MDS, DISTATIS and CA plots), the PCA bi-plots had to be modified so that they contained similar classes of sensory descriptors, as depicted in the respective sorting plots, i.e. 1) raw aroma; 2) raw appearance; 3) cooked appearance; 4) cooked texture; and 5) cooked aroma and flavour attributes.

As discussed, the MDS and DISTATIS plots indicated the grouping of samples based on similarity or dissimilarity of sensory attributes, whereas the CA plots indicated the sensory descriptors, assigned by the individual judges to the different groupings of samples (Fig. 1–5). A CA plot is interpreted in the same manner as a PCA bi-plot (Beh *et al*., 2011), i.e. highly correlated products and/or sensory attributes are in a close proximity with one another (Lawless & Heymann, 2010). Plots can be compared visually; however, RV coefficients can also be calculated to ascertain similarity of sample groupings. RV coefficients are measures that indicate the similarity between two product configurations. Generally, the RV coefficient can be considered a unifying tool for linear multivariate statistical methods (Robert & Escoufier, 1976). When coefficient values are close to 1, there is a very good agreement between configurations. Other authors concluded that a RV value close to 0.77 signifies a good agreement (Faye *et al*., 2004), while Tang and Heymann (2002) reported RV values of 0.68 as adequate. To assist in the interpretation of results in this study, the rice samples are marked in corresponding colours on all plots.

Figure 6 gives the RV coefficients, illustrating the overall similarity of the groupings of all the MDS, DISTATIS and CA plots shown in Fig. 1-5. The configuration agreement between DISTATIS and MDS had the highest RV value (0.90), followed by DISTATIS and CA (0.75) and lastly MDS and CA (0.74). The RV value of 0.90 indicates an extremely high degree of similarity of groupings in all the MDS and DISTATIS plots, illustrating that both these methods of analysis were highly appropriate for grouping long-grain parboiled rice, according to specific, classes of sensory attributes such as appearance or texture attributes. The RV values, when comparing DISTATIS and CA or MDS and CA, were slightly lower; however, these values, according to Faye *et al.,* (2004), still indicate a good agreement between the respective methods of analysis.

The RV values indicating the agreement of groupings between the PCA plots (Fig. 1d-5d) and the corresponding MDS, DISTATIS and CA plots, respectively, are indicated in Table 3 for the five classes of sensory attributes, i.e. raw aroma, raw appearance, cooked appearance, cooked texture, and cooked aroma and flavour.

The product groupings for *raw aroma* were not similar, when comparing the groupings illustrated in the PCA bi-plot (Fig. 1d) to those of the MDS (Fig. 1a), DISTATIS (Fig. 1b) and CA plots (Fig. 1c). The extremely low RV values (Table 3) substantiate this lack of grouping when comparing the respective methods of analysis.

The product groupings for *raw appearance* were fairly similar when comparing the groupings, illustrated in the PCA bi-plot (cooked and raw appearance) (Fig. 2d) to those of the MDS plot (Fig. 2a), DISTATIS (Fig. 2b) and CA plots (Fig. 2c). The samples that disagreed between the PCA bi-plot grouping and that of the MDS and DISTATIS plot grouping were Arroz, HDawn, Indian and PY, while in the CA plot, only PY disagreed. This might be due to the fact that the cooked appearance was dominating the grouping of certain products. Since raw appearance only had one descriptor, a PCA bi-plot could not be generated and it was decided to group both raw and cooked appearance descriptors together into a single PCA bi-plot. When comparing the respective methods of analysis, relatively high RV value confirmed the similarity of the evident grouping (Table 3).

Based on these results, it was evident that sorting was not a good replacement for DSA when analysing raw rice aroma, but it could be used to profile raw rice appearance successfully. Table 4 indicates the mean values for the various raw aromas, analysed by DSA in Chapter 3. From these results it was evident that mean values were very low for most of the aroma descriptors, with the exception of "typical rice aroma". During DSA, the majority of these raw aroma descriptors were disregarded, as their intensities were barely perceptible and thus too low to draw any conclusions from. This might well indicate that the low intensities of the samples were barely perceptible during the sorting task as well and, hence, not a good measure to sort by.

The product grouping for *cooked appearance* was similar, when comparing the groupings illustrated in the PCA bi-plot (cooked and raw appearance) (Fig. 3d) to those of the MDS (Fig. 3a), DISTATIS (Fig. 3b) and CA plots (Fig. 3c). The sample that disagreed with the PCA bi-plot grouping and the MDS plot grouping was AM. In the DISTATIS plot, grouping both Arroz and AM were in disagreement, while only Arroz was in disagreement in the CA plot. RV values indicated relatively good agreement between the various statistical methods; the MDS and CA plots showed the best agreement with DSA (RV = 0.64).

The product grouping for *cooked texture* was fairly similar, when comparing the groupings illustrated in the PCA bi-plot (Fig. 4d) to those of the MDS (Fig. 4a), DISTATIS (Fig. 4b) and CA plots (Fig. 4c). The only samples that disagreed between the grouping of the PCA bi-plot and the various sorting plots were the following: Tastic in the MDS plot; Tastic and Spekko in the DISTATIS plot; and Arroz, PY, RiceL, WW and Indian in the CA plot. The high RV coefficients substantiated the similar groupings, when comparing the respective methods of analysis, with the CA plot having the best agreement with the DSA configuration (RV = 0.82).

The product grouping for *cooked aroma and flavour* was not that similar, when comparing the groupings in the PCA bi-plot (Fig. 5d) to those of the MDS (Fig. 5a) and DISTATIS (Fig 5b) plots. The only clearly corresponding clustering that was evident between both plots with the PCA bi-plot, was WW and RiceL. The grouping comparison between the PCA bi-plot (Fig. 5d) and CA plot (Fig. 5c) indicated a better similarity between the two plots, in terms of sample configuration. The only product that disagreed between the two plots was Spekko. RV coefficients indicated relatively good similarity between the configurations of the different statistical methods, with CA showing the best agreement (RV = 0.71).

Based on these results it was evident that sorting is a good alternative to DSA when profiling cooked rice classes and can be used as an efficient and economical method of obtaining information about sensory differences among food products (Abdi *et al*., 2007). The high RV coefficients confirmed the similarity in grouping, which was visually illustrated by comparing the various plots.

Conclusions

Sorting can be successfully used, as a rapid profiling method for the broad-based classification of long-grain parboiled rice, as an alternative to DSA for most attributes, with the exception of raw rice aroma. The low RV values for raw rice aroma confirmed the poor similarity, evident when the various plots were compared. Sorting provides qualitative information, whilst DSA produces quantitative information; hence the suitability of sorting, as a rapid profiling method, depends largely on what the objective of the study to be undertaken is. This research indicated that a protocol for the rapid broad-based profiling of long-grain parboiled rice can be constructed for the South African rice industry.

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Table 1 Twelve long-grain parboiled rice samples used in the study.

Country of origin	Conventional name	Abbreviation/name used in this study
North America	Riceland	RiceL
	Woolworths	WW
India	Indian	Indian
	Harvest Dawn	HDawn
Vietnam	Vietnam	Vietn
Thailand	Tasia	Tasia
	Spekko	Spekko
	Tastic	Tastic
	Aunt Caroline	AC
South America	Americano	AM
	PY	PY
	Arroz	Arroz

Table 2 Classes of sensory attributes and descriptors that were used as input for the statistical analysis of the sorting data.

Raw aroma	Raw appearance	Cooked appearance	Cooked texture	Cooked aroma and flavour
Stale/Dusty	Long kernel	Off white colour	Dry	Hay like aroma
Dusty	Light yellow colour	Loose grains	Rubbery	Buttery flavour
Maize kernel	Yellow colour	Slightly sticky	Loose grain	Sour aroma
Crushed whole maize	Golden colour	Very white	Firm	Toasted aroma
Oily	Dark spots	Sticky	Typical rice	Typical rice aroma
Raw starch	Small grain sizes	White colour	Slightly sticky	Cooked maize porridge flavour
Typical rice	White colour	Plump	Soft	Bland flavour
Bland	Light colour	Starchy	Sticky	Cooked maize porridge
Sour	Uneven colour		Plump	Typical rice
Raw oats			Starchy	Typical rice flavour

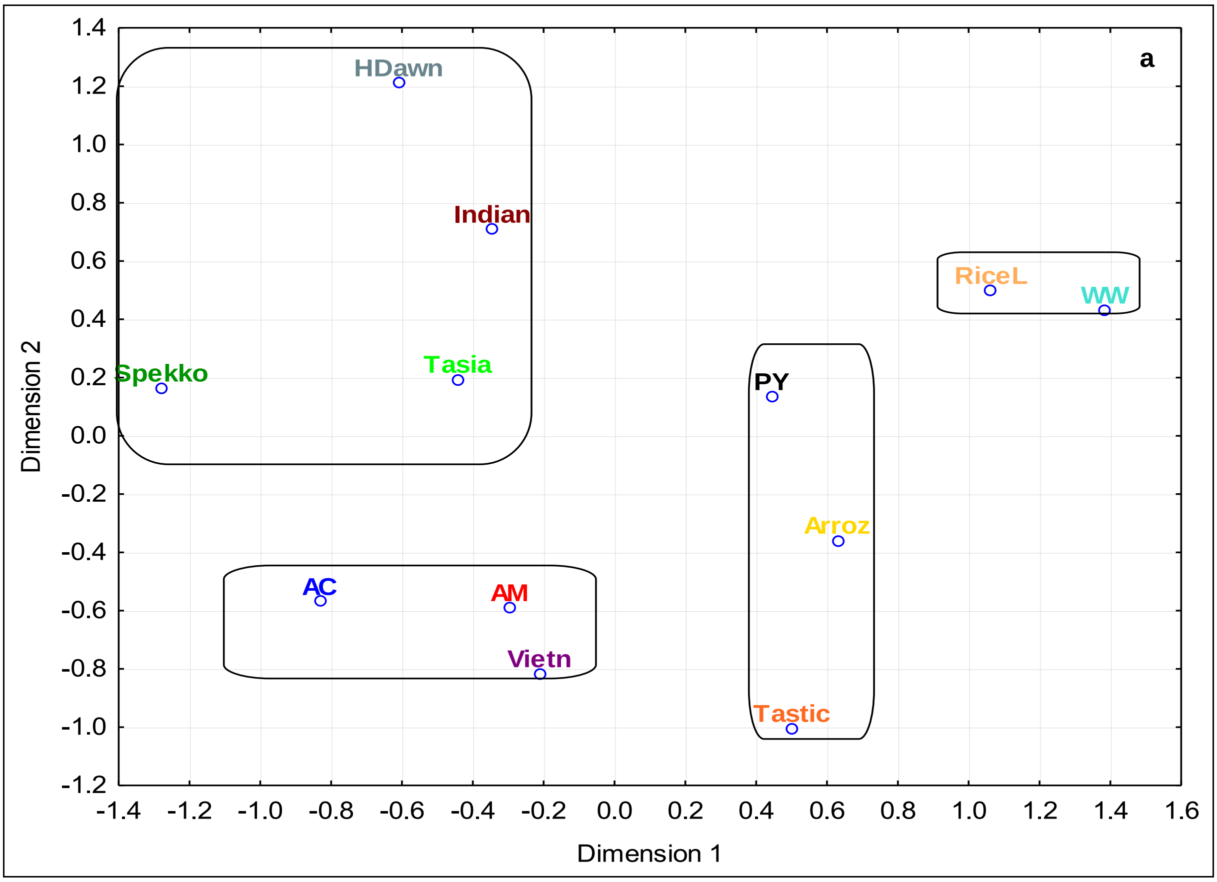
Table 3 RV coefficients indicating similarity between product configurations for the different classes of sensory attributes measured.

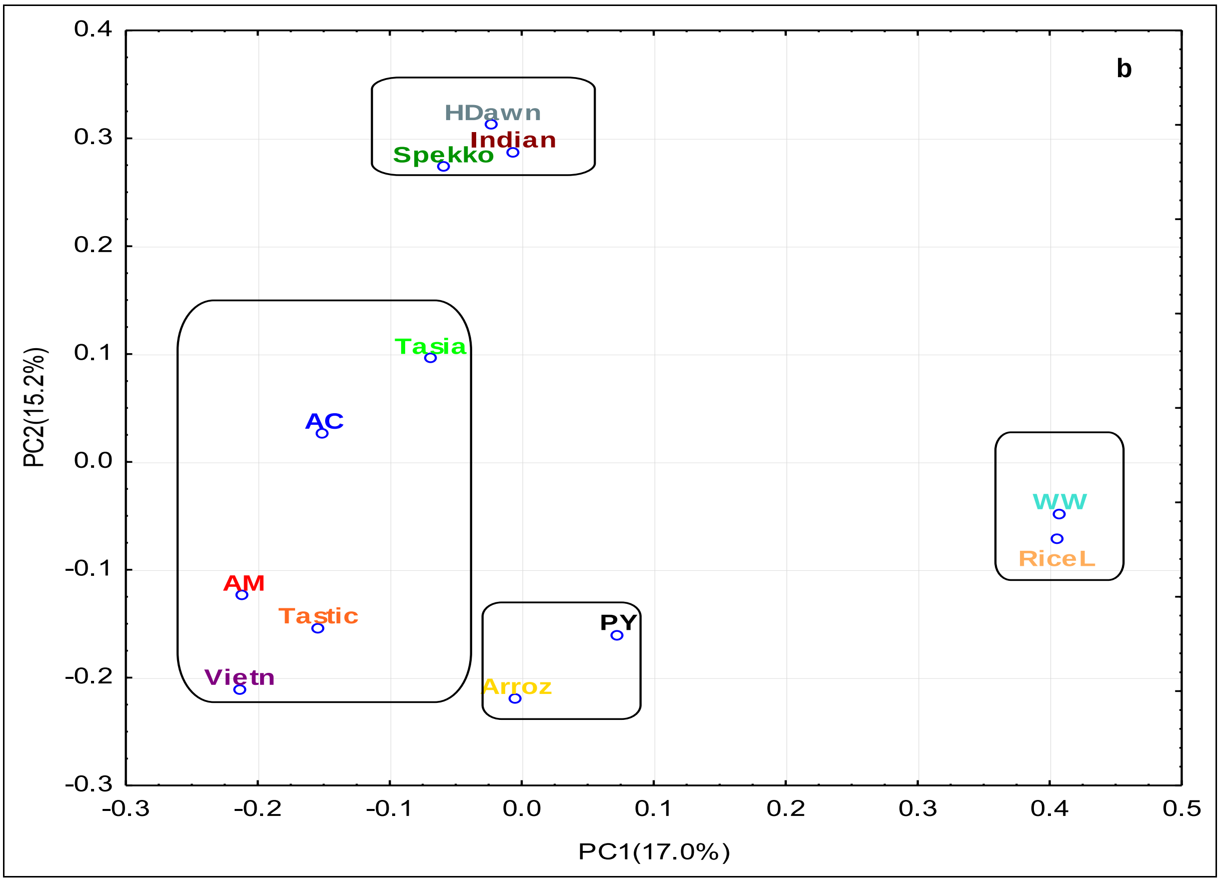
DSA attribute groupings as indicated by PCA bi-plots	Sorting attribute groupings indicated by MDS, DISTATIS and CA plots	RV coefficients
Raw aroma	MDS	0.14
	DISTATIS	0.19
	CA	0.17
Raw and cooked appearance	MDS[a]	0.67
	DISTATIS[a]	0.69
	CA[a]	0.71
Cooked and raw appearance	MDS[b]	0.64
	DISTATIS[b]	0.59
	CA[b]	0.64
Cooked texture	MDS	0.66
	DISTATIS	0.72
	CA	0.82
Cooked aroma and flavour	MDS	0.53
	DISTATIS	0.64
	CA	0.71

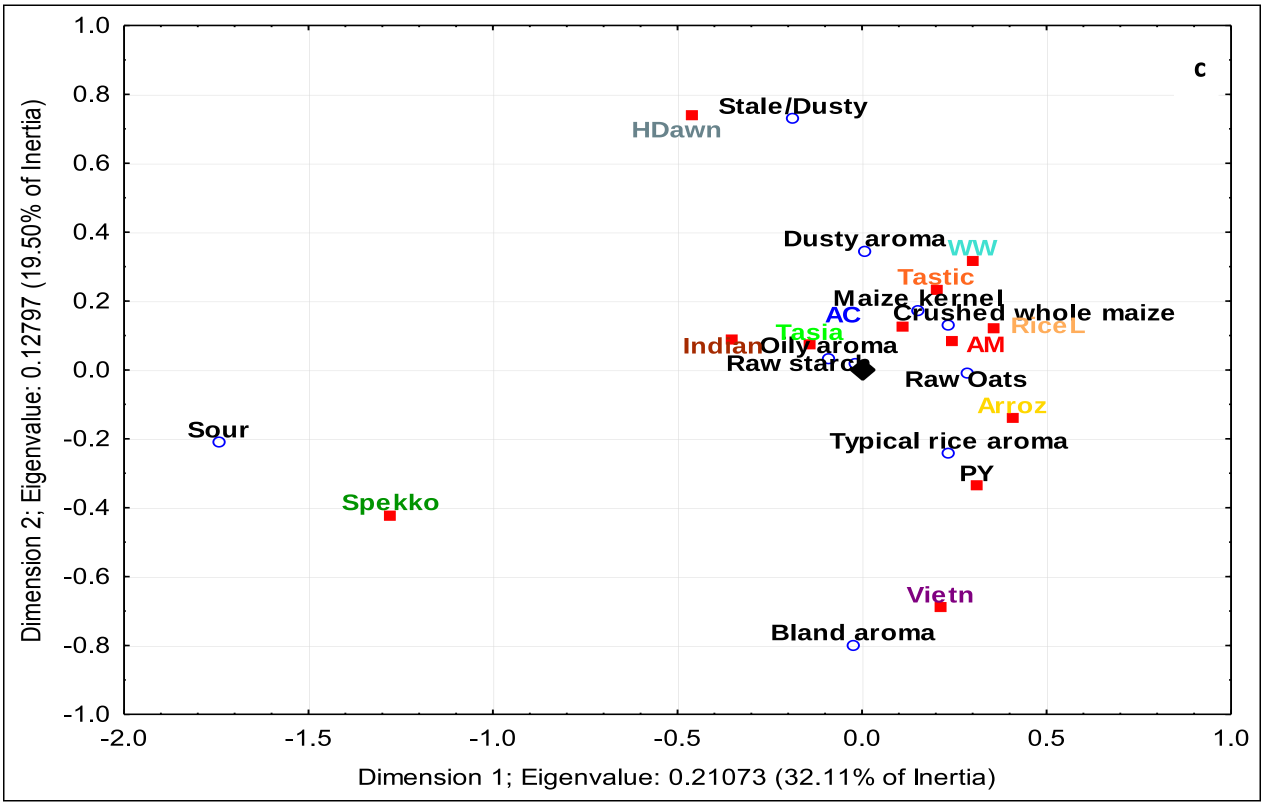
[a]Sorting class: raw appearance; [b]Sorting class: cooked appearance.

Table 4 Minimum, maximum, mean and standard deviations of raw aroma attributes as derived from DSA.

Variable	Minimum	Maximum	Mean	Standard deviation
Typical rice	21.13	42.80	32.18	7.28
Crushed whole maize kernel	1.87	21.33	10.84	4.99
Raw oats	0.93	13.26	5.50	4.58
Sour	0.00	10.68	2.83	3.34
Stale/Dusty	3.00	18.00	7.97	4.36
Oily	0.37	14.07	6.54	4.25


a
HDawn
Indian
Spekko
Tasia
RiceL
WW
PY
Arroz
AC
AM
Vietn
Tastic
Dimension 2
Dimension 1
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
-1.2
-1.4
-1.2
-1.0
-0.8
-0.6
-0.4
-0.2
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6


b
HDawn
Indian
Spekko
Tasia
AC
WW
RiceL
AM
Tastic
PY
Vietn
Arroz
PC2(15.2%)
PC1(17.0%)
0.4
0.3
0.2
0.1
0.0
-0.1
-0.2
-0.3
-0.3
-0.2
-0.1
0.0
0.1
0.2
0.3
0.4
0.5



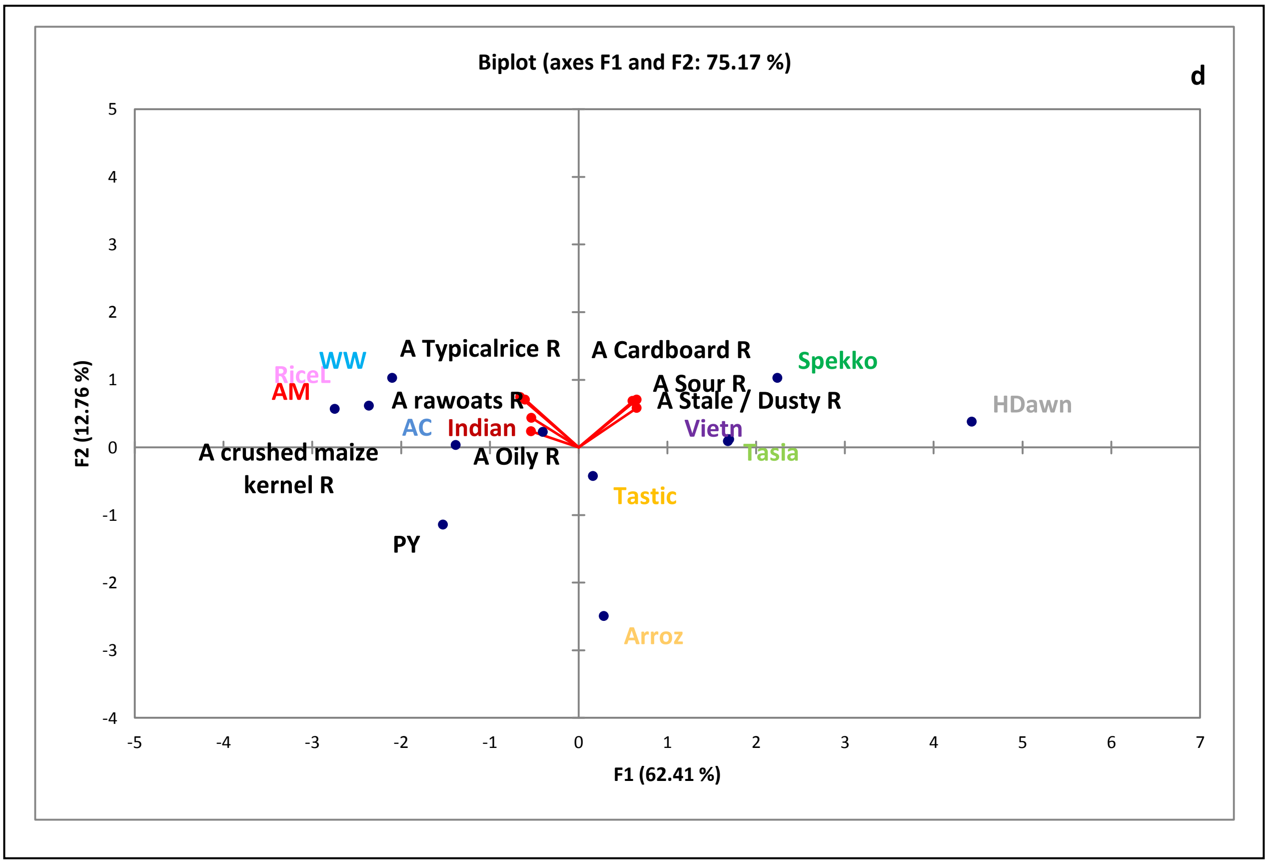
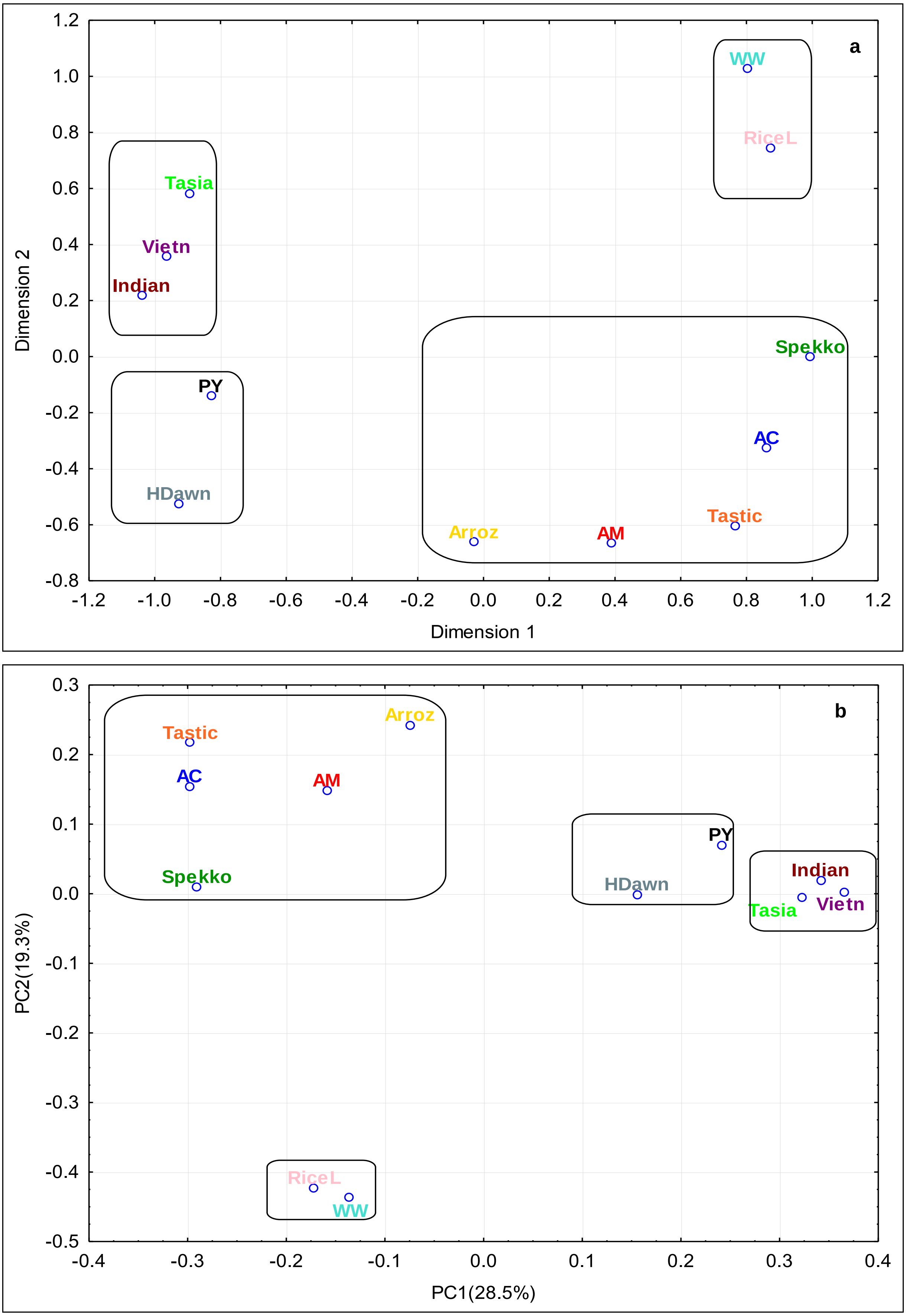


Fig. 1a) MDS plot for raw aroma, **b)** DISTATIS plot for raw aroma, **c)** CA plot for raw aroma (all based on rapid methods) and **d)** PCA bi-plot for raw aroma (based on DSA data) of 12 long-grain parboiled rice samples. The rice samples are marked in corresponding colours in all plots. The letters "A", "F" and "T" before the attribute denote aroma, flavour and texture, whilst the "C" and "R" refer to the cooked or raw attribute.


a
Dimension 1
Dimension 2
WW
RiceL
Tasia
Vietn
Indian
PY
HDawn
Spekko
AC
Tastic
Arroz
AM
b
PC1(28.5%)
PC2(19.3%)

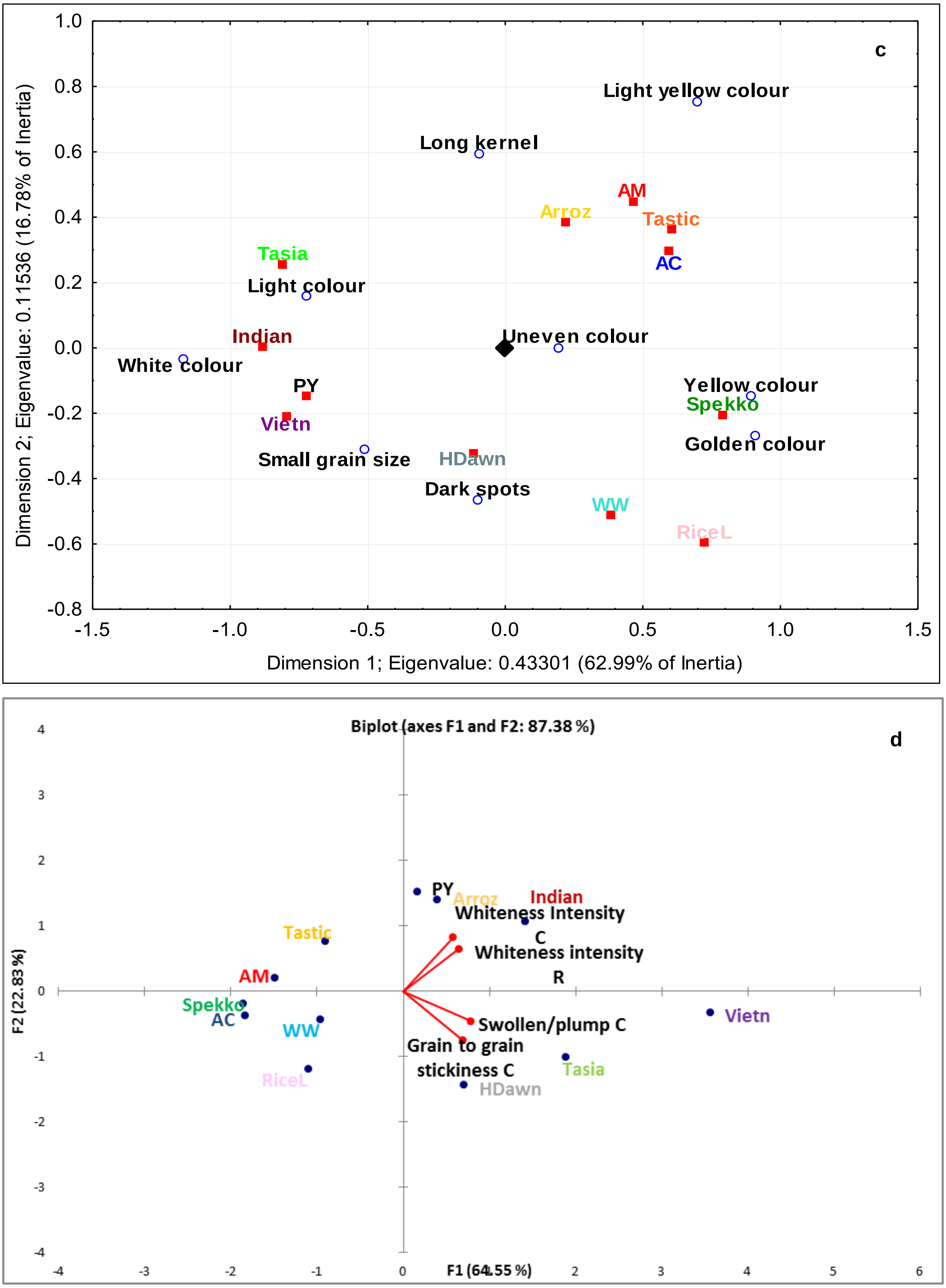
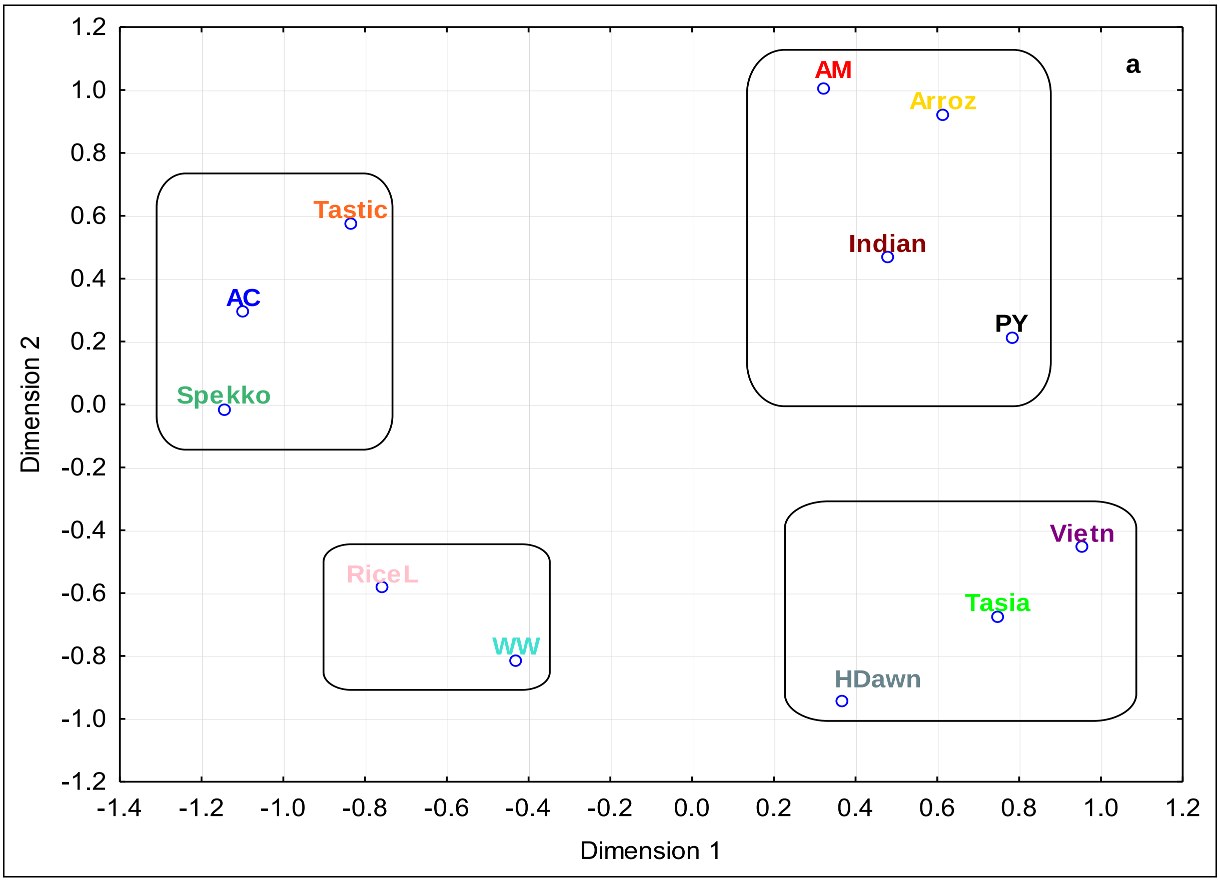
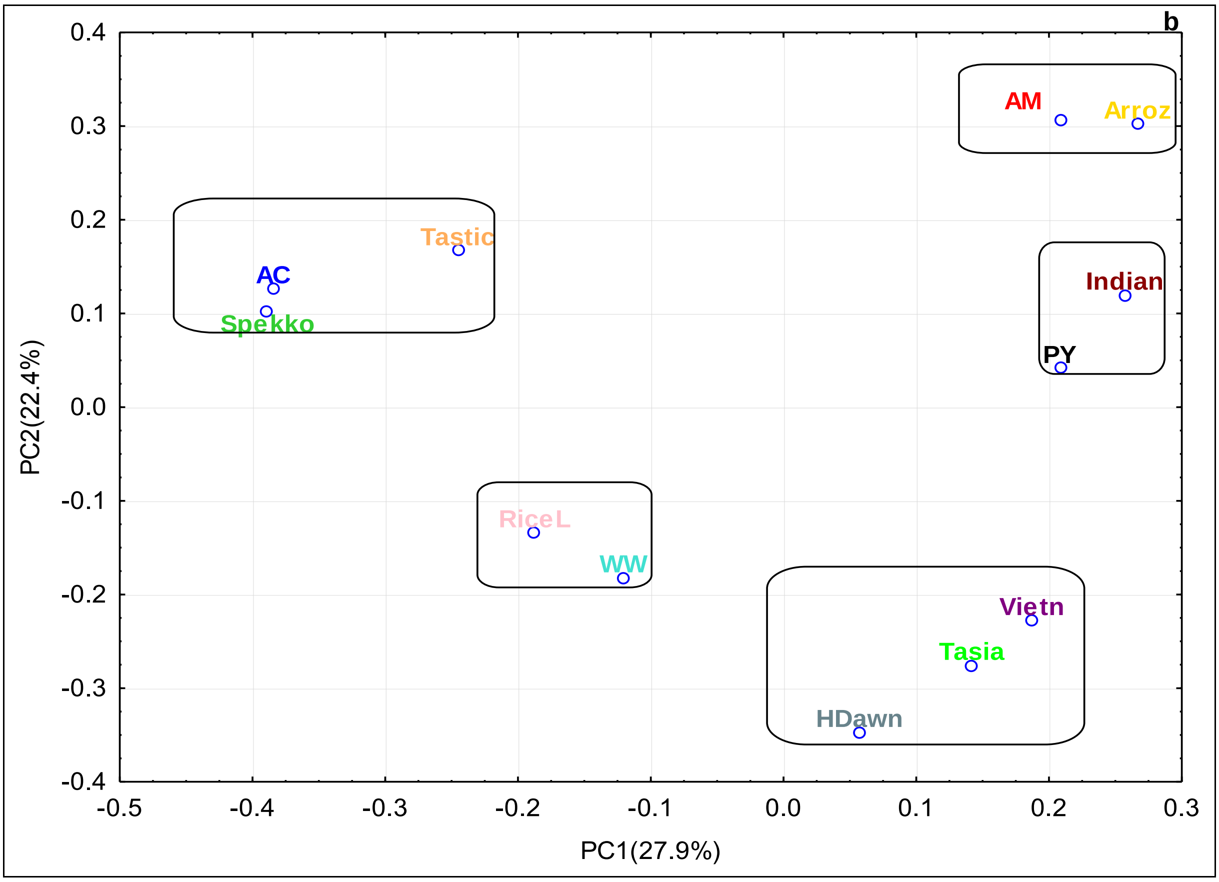
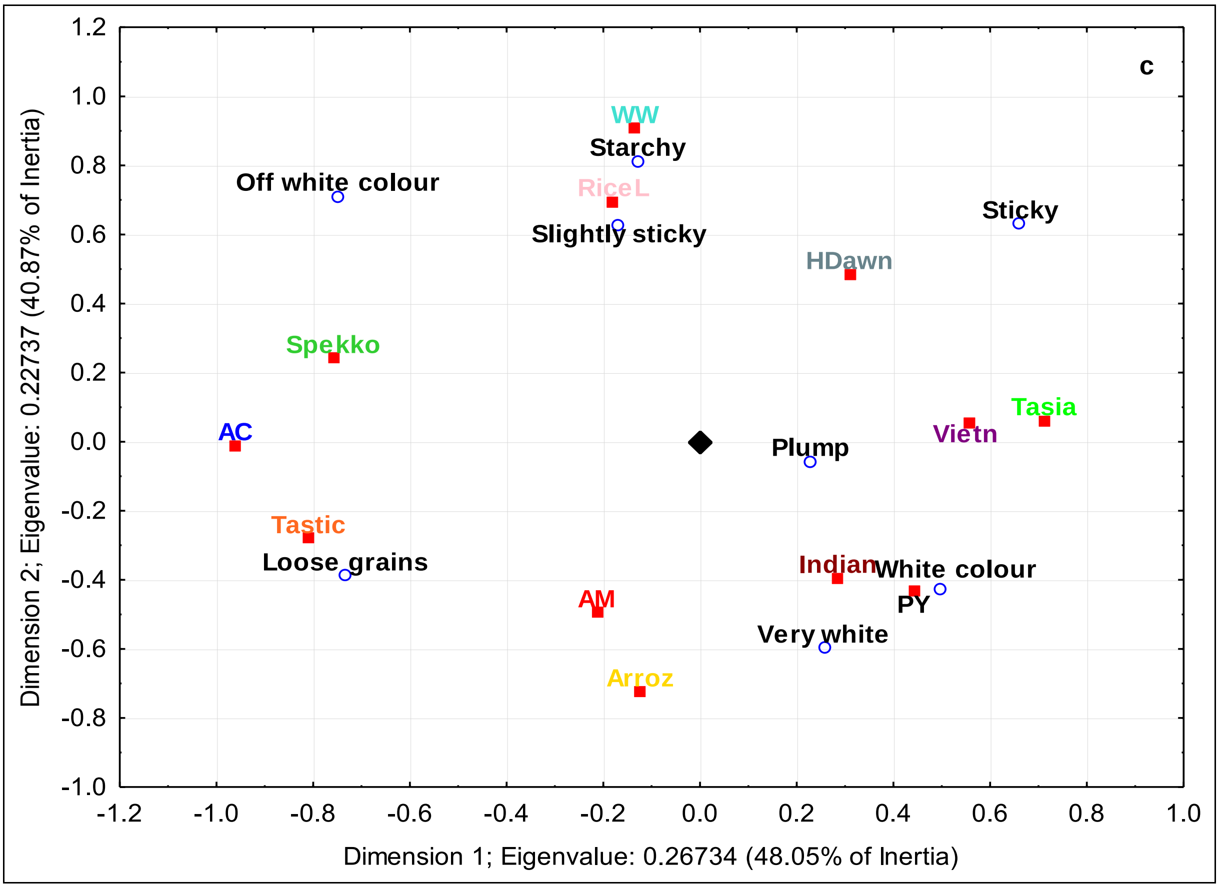


Fig 2a) MDS plot for raw appearance, **b)** DISTATIS plot for raw appearance **c)** CA plot for raw appearance (all based on rapid methods) and **d)** PCA bi-plot for raw and cooked appearance (based on DSA data) of 12 long-grain parboiled rice samples. The rice samples are marked in corresponding colours in all plots. The letters “A”, “F” and “T” before the attribute denote aroma, flavour and texture, whilst the “C” and “R” refer to the cooked or raw attribute.


a
Dimension 2
Dimension 1
AM
Arroz
Tastic
AC
Spekko
Indian
PY
RiceL
WW
Vietn
Tasia
HDawn


b
PC2(22.4%)
PC1(27.9%)
AM
Arroz
Tastic
AC
Spekko
Indian
PY
RiceL
WW
Vietn
Tasia
HDawn



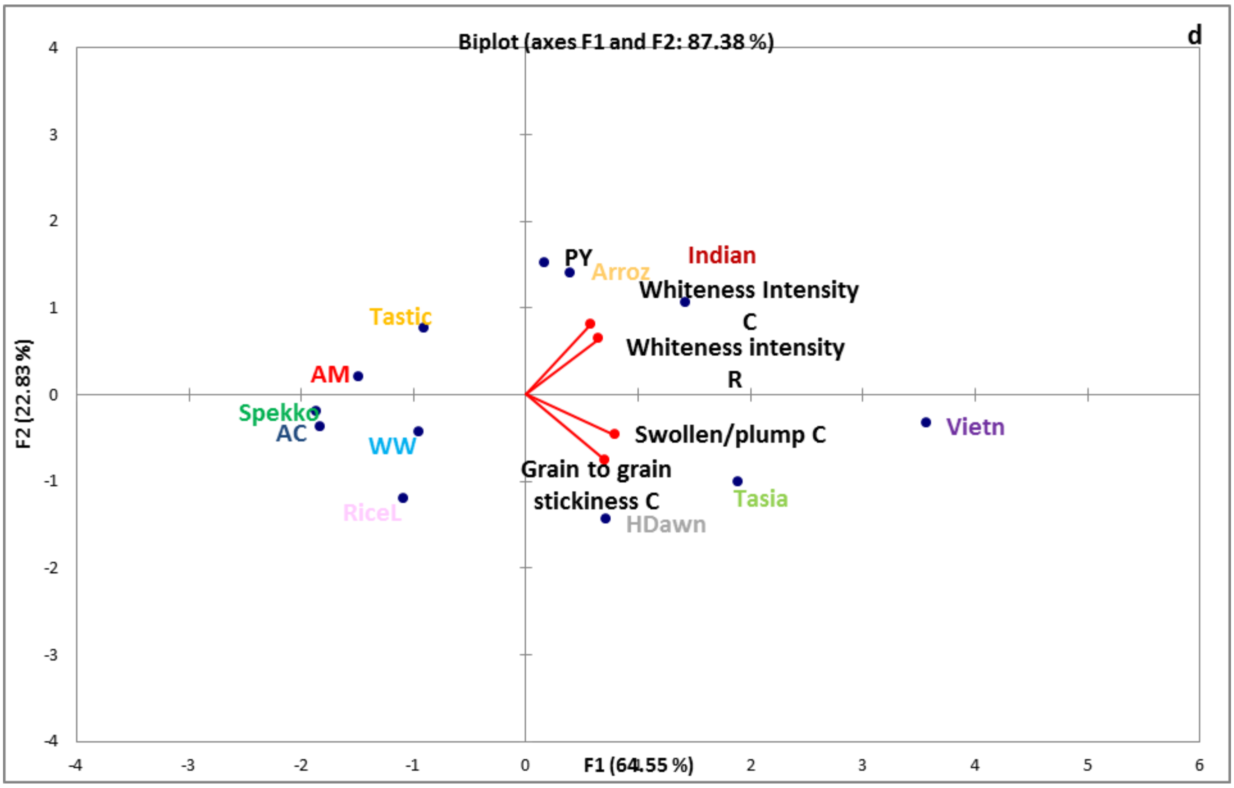
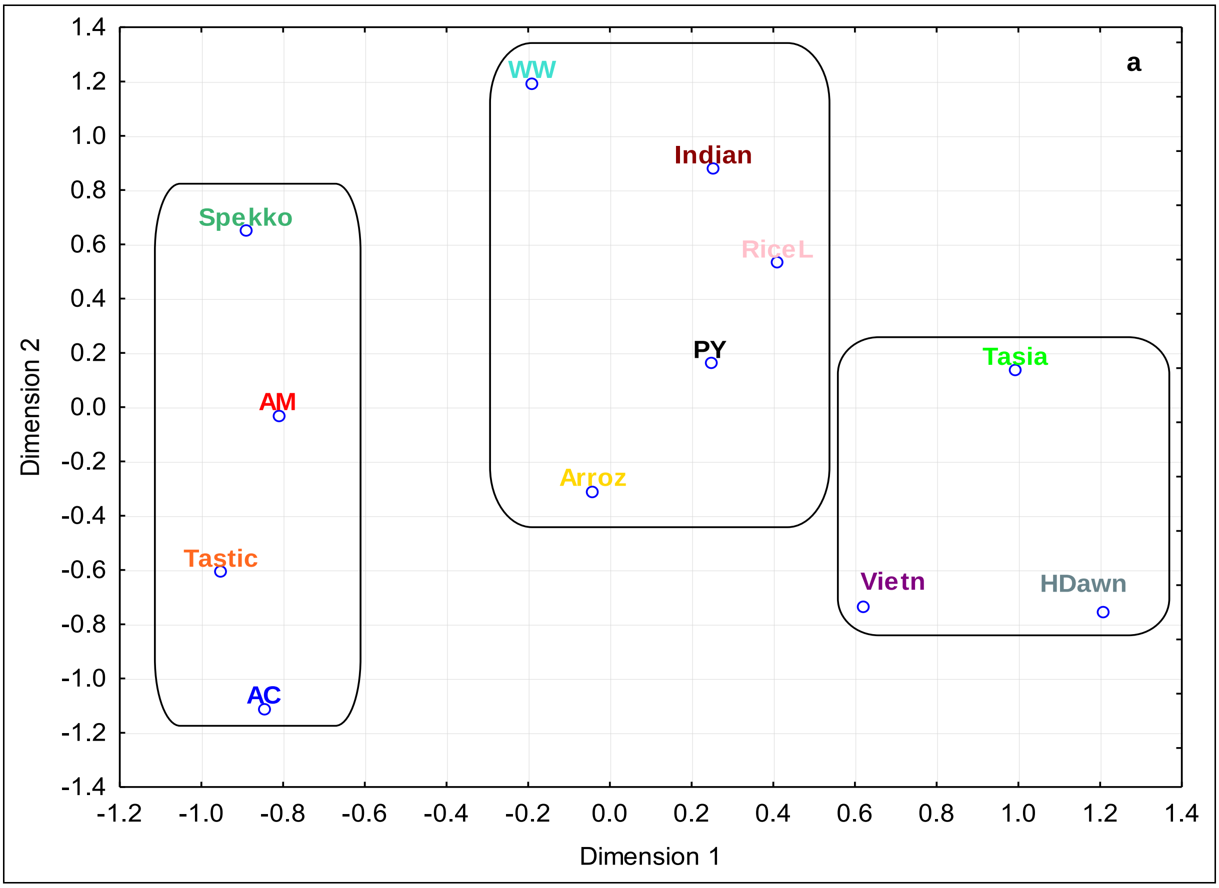
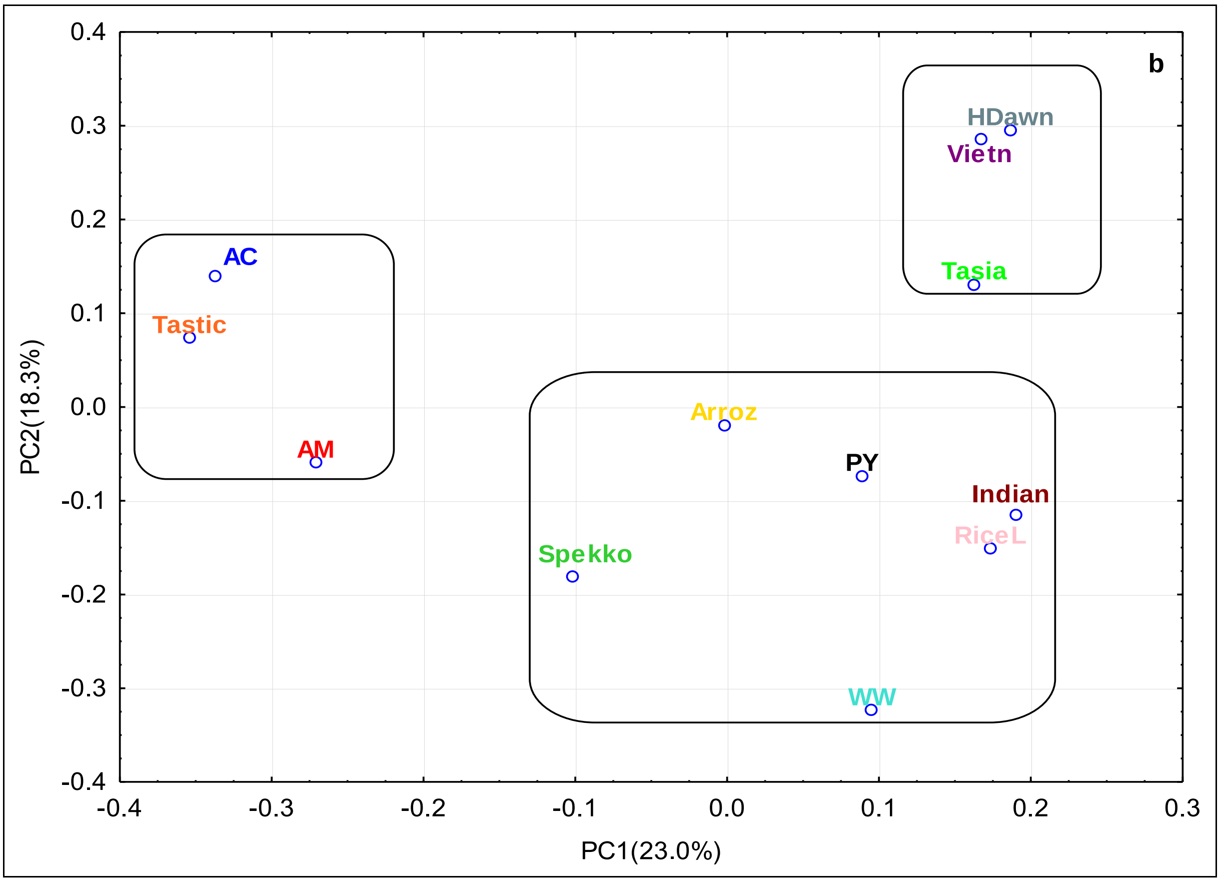
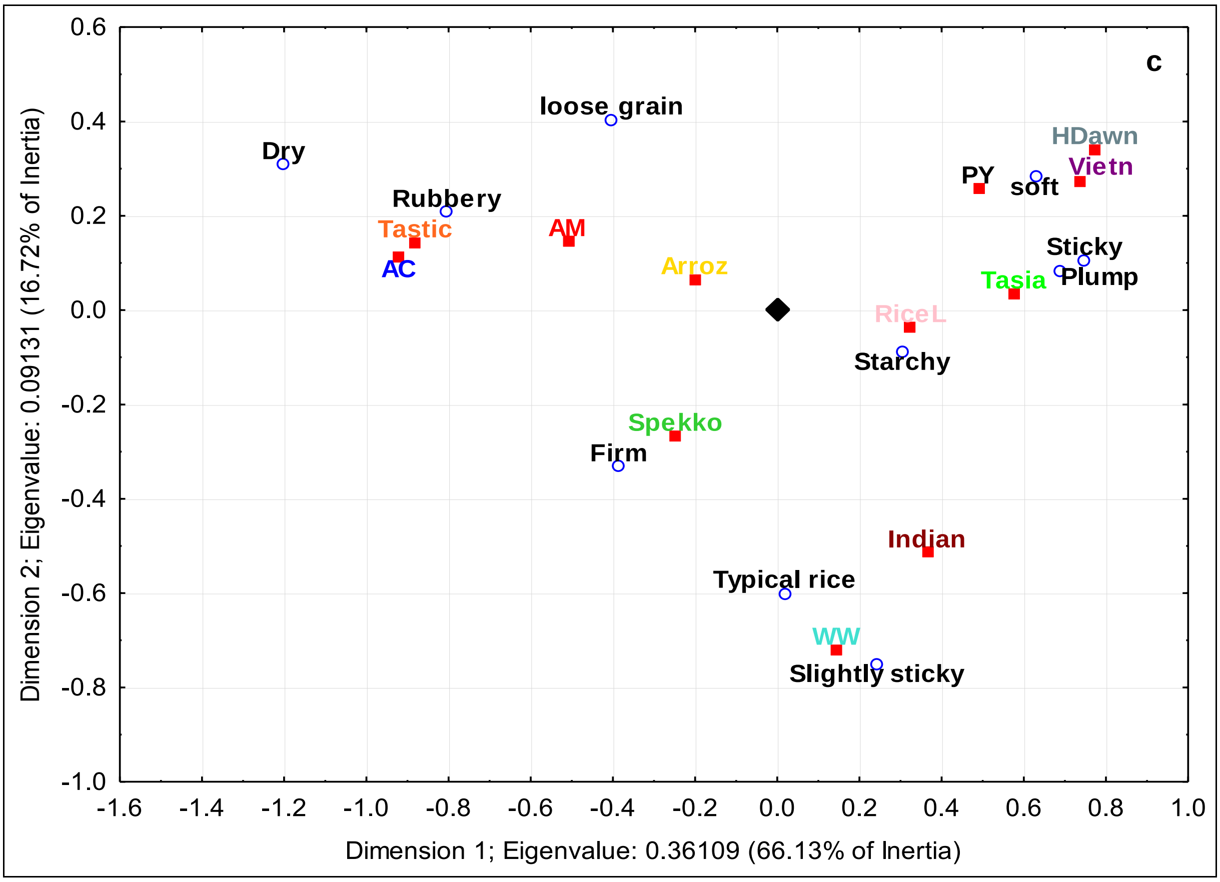


Fig. 3a) MDS plot for cooked appearance, **b)** DISTATIS plot for cooked appearance, **c)** CA plot for cooked appearance (all based on rapid methods) and **d)** PCA bi-plot for raw and cooked appearance (based on DSA data) of 12 long-grain parboiled rice samples. The rice samples are marked in corresponding colours in all plots. The letters "A", "F" and "T" before the attribute denote aroma, flavour and texture, whilst the "C" and "R" refer to the cooked or raw attribute.


a
Dimension 1
Dimension 2
WW
Indian
Spekko
RiceL
PY
Tasia
AM
Arroz
Tastic
Vietn
HDawn
AC


b
PC1(23.0%)
PC2(18.3%)
HDawn
Vietn
AC
Tasia
Tastic
Arroz
AM
PY
Indian
RiceL
Spekko
WW



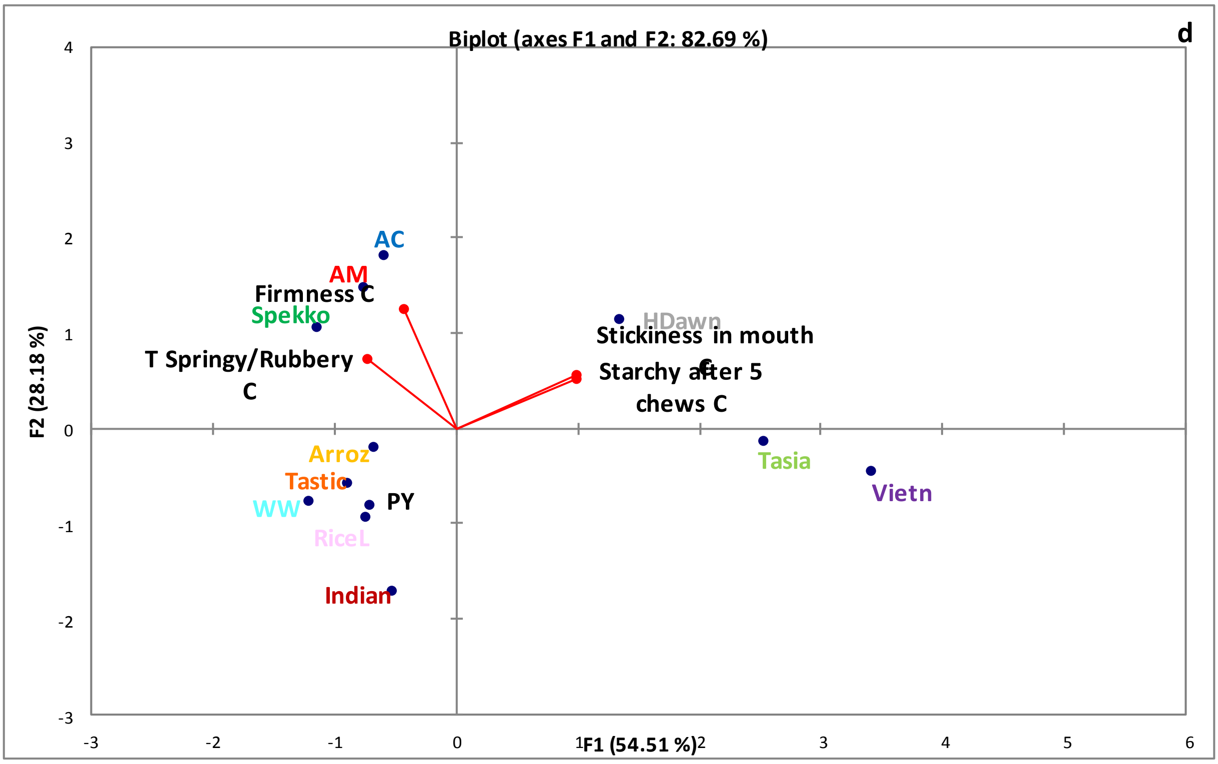
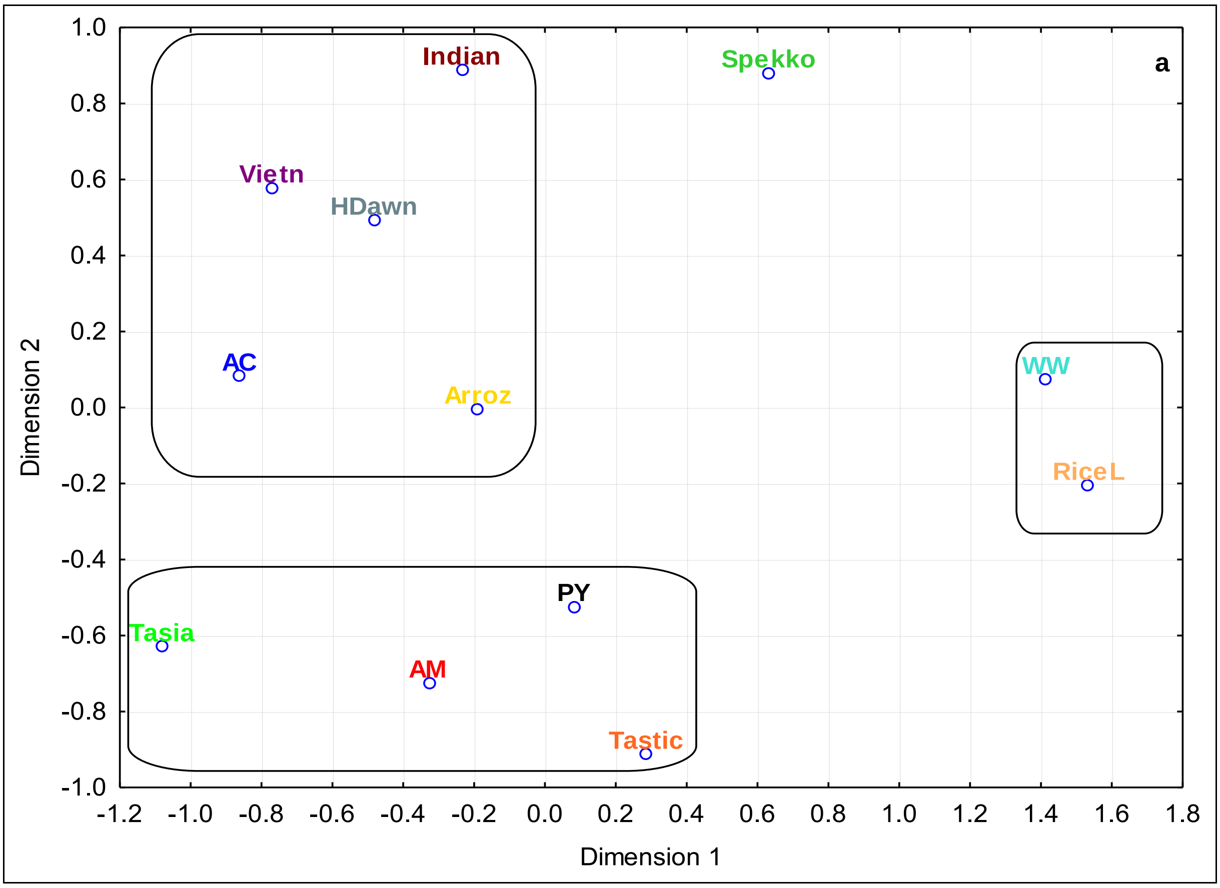
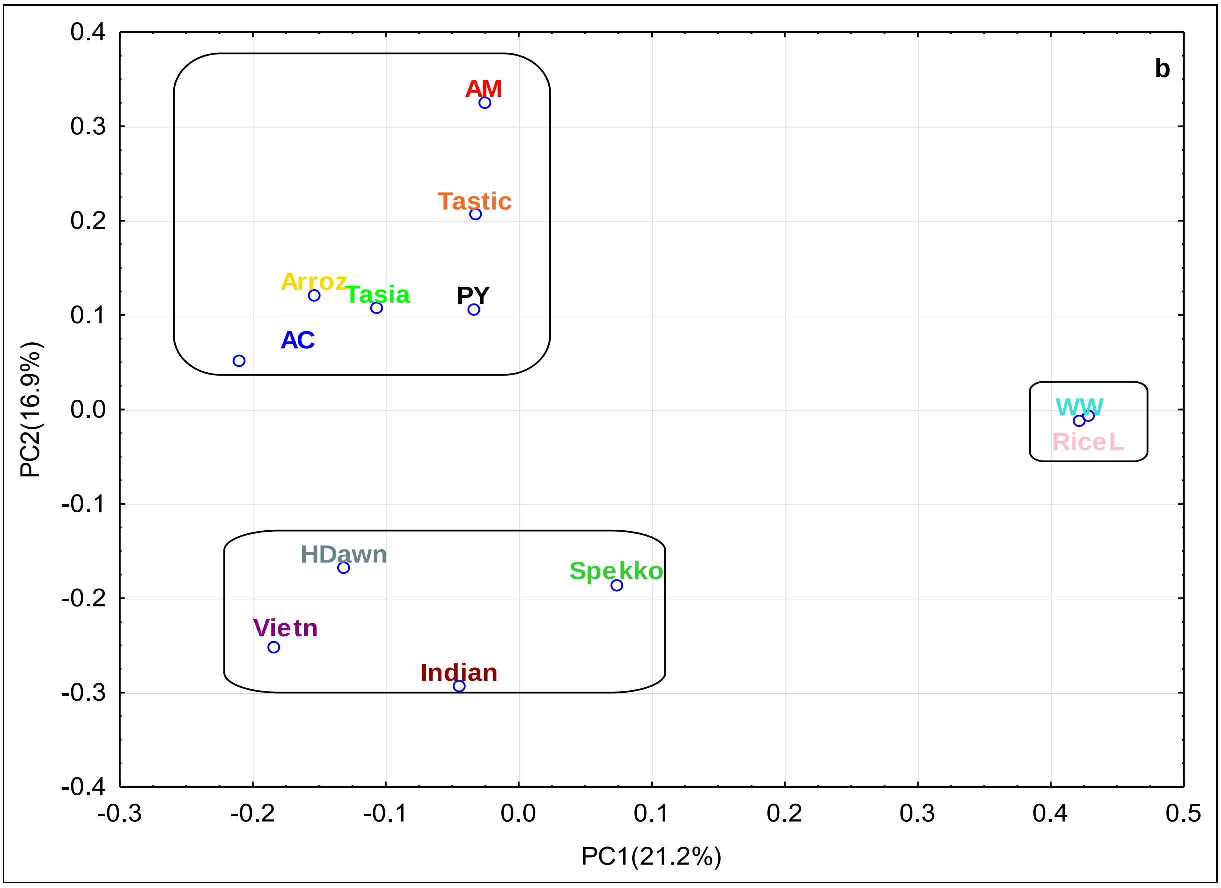
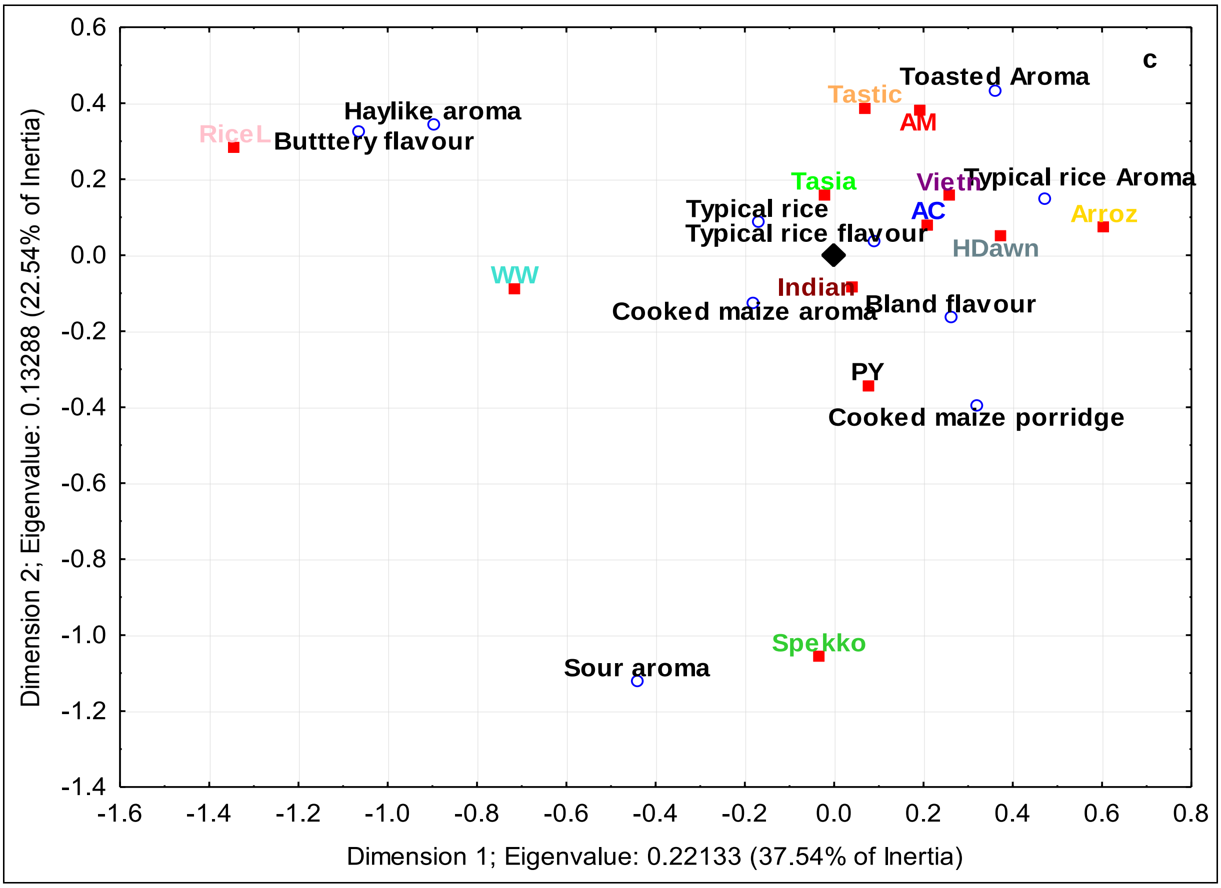


Fig. 4a) MDS plot for cooked texture, **b)** DISTATIS plot for cooked texture **c)** CA plot for cooked texture (all based on rapid methods), **d)** PCA bi-plot for cooked texture (based on DSA data) of 12 long-grain parboiled rice samples. The rice samples are marked in corresponding colours in all plots. The letters "A", "F" and "T" before the attribute denote aroma, flavour and texture, whilst the "C" and "R" refer to the cooked or raw attribute.


a
Dimension 1
Dimension 2
Indian
Spekko
Vietn
HDawn
AC
Arroz
WW
RiceL
PY
Tasia
AM
Tastic
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
-1.2
1.2
1.4
1.6
1.8


b
PC1(21.2%)
PC2(16.9%)
AM
Tastic
Arroz
Tasia
PY
AC
WW
RiceL
HDawn
Spekko
Vietn
Indian
0.4
0.3
0.2
0.1
0.0
-0.1
-0.2
-0.3
-0.4
0.5



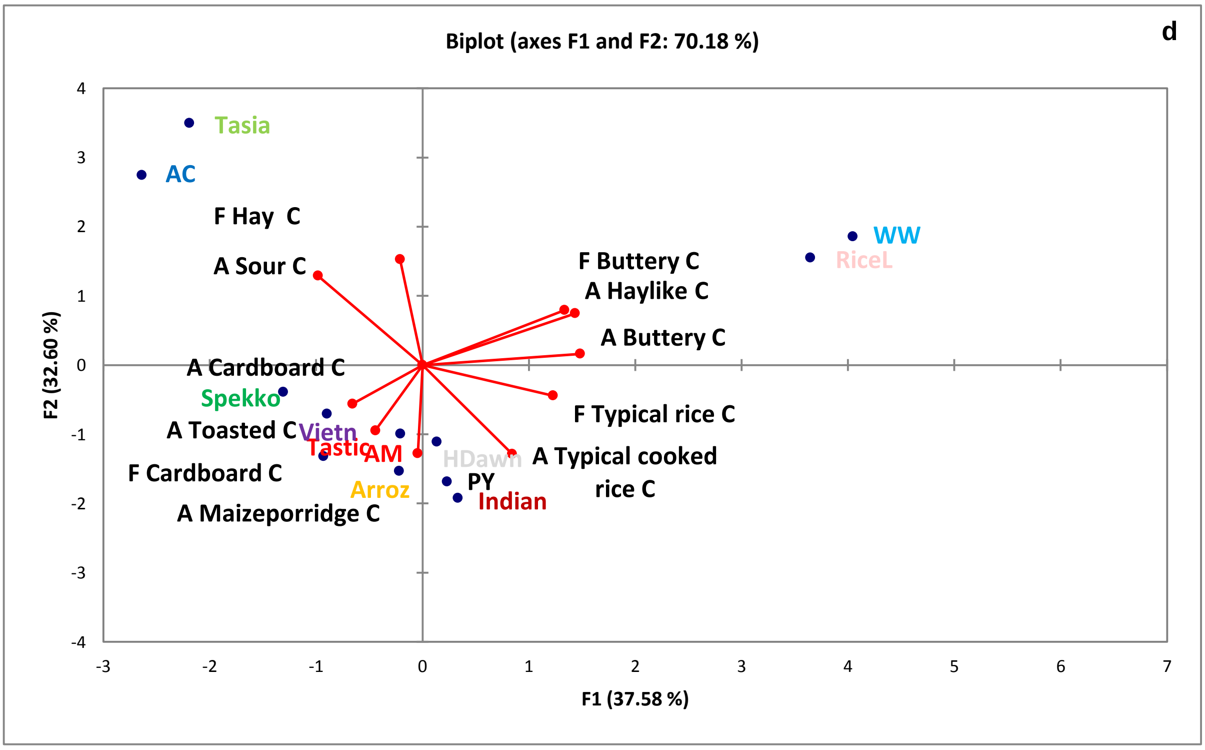


Fig. 5a) MDS plot for cooked aroma and flavour, **b)** DISTATIS plot for cooked aroma, **c)** CA plot for cooked aroma and flavour (all rapid methods) and **d)** PCA bi-plot for cooked aroma and flavour (based on DSA data) of 12 long-grain parboiled rice samples. The rice samples are marked in corresponding colours in all plots. The letters “A”, “F” and “T” before the attribute denote aroma, flavour and texture, whilst the “C” and “R” refer to the cooked or raw attribute.

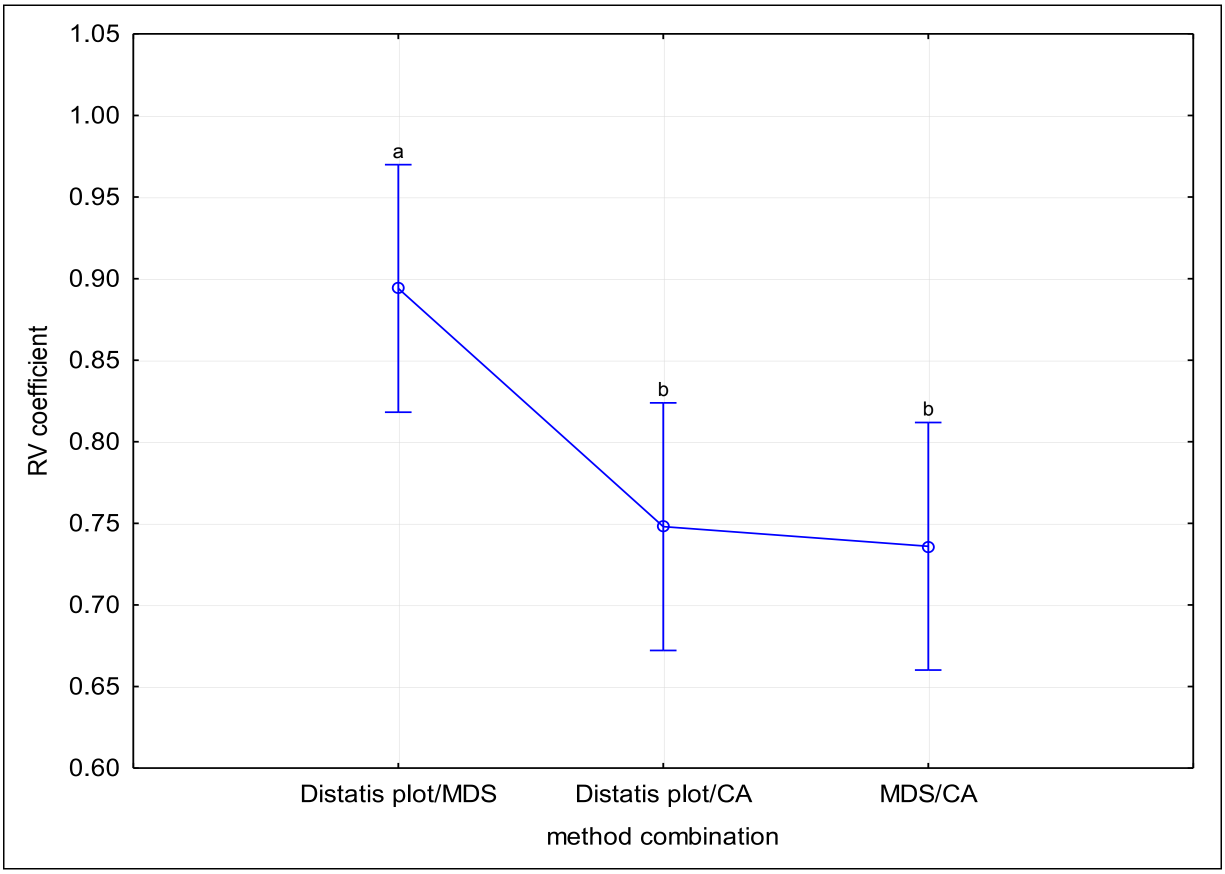


Fig. 6 RV coefficients indicating similarity between product configurations of different statistical methods when analysing sorting data.

ADDENDUM 2 – Sorting instructions for panel

SORTING

Day 1: 3 December 2013

SESSION 1: Uninstructed sorting of rice according to cooked aroma and flavour.

Please read through the instructions carefully and do not hesitate to ask if you encounter any difficulties during the process.

INSTRUCTIONS

-You have been presented with 12 samples labelled from 13-24

-The samples are all long grain parboiled white rice.

-Please sort the samples according to the **SIMILARITY OF THEIR COOKED AROMA & FLAVOUR.**

-You are allowed to **taste & smell** at the samples as many times as you like, and in any order.

-On the large A3 paper provided group together the samples that similarities in appearance.

-You may form as many groups as you wish, **BUT NOT MORE THAN 6 GROUPS.**

-Each group may contain as many samples as you like.

-Once you have assigned all the samples to a group, use the table provided on the separate A4 page to indicate which samples you have grouped together.

-Then please write down the major **AROMA & FLAVOUR attributes associated with each of the sample groups**. Where appropriate please indicate if attributes contain high/low/zero levels of the attribute/s.

-**Do not use more than 5 attributes** to describe the cooked aroma & flavour associated with each group.

Name: ____

Complete the table below by indicating which samples you have placed in the respective groups.
Then please write down the major AROMA & FLAVOUR attributes associated with each group in the columns on the right.

Group	Samples									Appearance attributes associated with the groups.	
										1	4
										2	5
1										3	
										1	4
										2	5
2										3	
										1	4
										2	5
3										3	
										1	4
										2	5
4										3	
										1	4
										2	5
5										3	
										1	4
										2	5
6										3	

THANK YOU FOR YOUR PARTICIPATION!

CHAPTER 5

LONG-GRAIN PARBOILED RICE:

DRIVERS OF CONSUMER LIKING

Abstract

The parboiled rice market in South Africa is becoming more competitive, with the increase of rice imports and new brands emerging. It is, therefore, of paramount importance to understand consumer preferences for long-grain parboiled rice, in order to remain competitive and not only retain, but gain market share. A quantitative and qualitative consumer investigation was undertaken in this study. During the quantitative investigation the preferences, with respect to eight long-grain parboiled rice samples (both raw and cooked), were determined on a nine-point hedonic scale, while the qualitative investigation examined consumer perceptions of and attitudes towards long-grain parboiled rice in general, using the focus group technique. The results indicated that the same three rice samples were preferred by consumers in both the raw and cooked format. The drivers of preference for these three rice samples can be attributed mainly to the rice having long, unbroken kernels, being white and clean, as well as being soft yet firm. The consumers highlighted the importance of cooked rice being loose and fluffy. The overall raw rice quality drivers were the uniformity of colour and grain size. Rice colour was preferred to be white and free from any dark spots. Long, unbroken grains were preferred. The overall cooked rice quality drivers were appearance and texture. White, loose and fluffy rice was preferred. The texture should be firm, yet soft and plump, but not sticky.

1. Introduction

Imports of long-grain parboiled rice into South Africa are increasing on a yearly basis, which makes it critical to remain competitive within the market place. South African consumers, interested in long-grain parboiled rice, can be classified as being part of either the non-premium or the premium long-grain parboiled rice purchasing category. The consumer interested in purchasing within the non-premium category can be regarded as being extremely price sensitive; this consumer does not really care much about consistent product quality. For this consumer, product quality should just be acceptable with each purchase. In contrast, the premium rice consumer is not very price sensitive; this consumer is willing to pay more, and furthermore, the product should be of a high, consistent quality with each purchase.

Consumer acceptance is an important element for a product to survive on the retail shelves (De Barcellos *et al*., 2010). Studies on consumer acceptability of long-grain parboiled rice, however, are limited (Demont *et al*., 2012). Previous studies have been undertaken in Ghana, where consumer preference for locally produced versus imported parboiled rice found that imported parboiled rice was preferred above the locally produced parboiled rice (Tomlins *et al.,* 2005). Consumer attitude towards and acceptability of parboiled rice in Brazil was also investigated, by making use of sensory panels and consumer surveys (Heinemann *et al*., 2006).

They found that Brazilians were mostly consuming non-parboiled rice. These consumers were, thus, unaware of the characteristics and advantages associated with parboiled rice. They also didn't seem to appreciate the sensory attributes associated with parboiled rice.

Perceived quality of a food product is shaped by many factors. When consumers evaluate food products and make purchasing decisions, they make use of an array of measures, such as price, sensory attributes (appearance, texture, flavour and aroma), health considerations, convenience, and recently, how a product is produced and processed, which includes its technological, ethical and social implications (Grunert *et al*., 2004; Grunert, 2005; Siegrist, 2007; Krystallis *et al*., 2009). External information, such as product characteristics displayed on the packaging, can be used to create consumer expectations. The first impression of food is mostly gathered from visual appearance. Kratochvil (1994) found that appealing colour and other visual attributes are the predominant factors in the consumers' willingness to purchase or consume a particular food. As soon as the product is consumed, the sensory characteristics experienced, together with the prior expectation, are combined into a global product quality evaluation (Lange *et al.,* 2000).

An array of methods, either qualitative or quantitative, can be used to gain insight into consumers' preferences. Qualitative research methods usually involve interviews or observations that are less structured than laboratory experiments. The most prolific form of qualitative research is focus group discussions. Focus group discussions usually involve about ten consumers, sitting around a table and discussing ideas or products in an informal manner, under the guidance of a moderator (Lawless & Heymann, 2010). The discussions are focused in such a way that certain issues are tabled for discussion, so the flow is not totally unstructured, but rather centred on the product, brand or concept. The data generated from focus groups are poorly suited to numerical analysis, primarily because focus group data are regarded as subjective and non-statistical (Chambers & Smith, 1991). Qualitative research, focusing on consumer perceptions, has several advantages. Firstly, the focus group can be probed to any depth required. This can lead to issues being raised, attitudes probed and underlying feelings and motivations uncovered. Consumers can voice their opinions and beliefs more freely, than in a formal directed questionnaire approach. The presence of the moderator enables issues that have not been anticipated beforehand to be followed up on the spot, since the interview flow is usually quite flexible. The second advantage is that interaction is possible between participants. One participant's remark may bring an issue to mind in a fellow participant. The group will often form its own dynamics, with participants discussing and contrasting product opinions, and in some cases, even arguing about product issues, characteristics and experiences. In a successful focus group these interactions will occur with minimal direction from the moderator. Another apparent advantage of focus group research is that it is quick to conduct. In practice these advantages are, however, rarely realised, as multiple groups need to be conducted, often in multiple locations, which involves travel and associated costs for moderators and all involved. The recruitment and screening of consumers is also a laborious task (Krueger & Casey, 2009). Qualitative consumer research can precede or follow quantitative research and both research types gain more validity, once they can be used together on a research problem (Chambers & Smith, 1991). Research done by De Barcellos *et al*. (2010) determined European consumers' acceptance of beef processing technologies, by making use of a focus group study, where they specifically explored consumers' attitudes, risk aversion and innovativeness.

A well-known example of a quantitative consumer research tool, especially when the aim is to test consumers' degree of liking, i.e. preference, as well as acceptability of a range of products, is the nine-point hedonic scale. Tomlins *et al. (*2005) made use of the nine-point hedonic scale in a study which investigated cooked rice acceptability among consumers in West Africa; so did Manickavasagan *et al*. (2013), when they investigated replacing white rice with brown rice in breakfast cereal named *idli* (savoury breakfast cake widely consumed in India). The hedonic scale, a powerful research tool, was originally invented and validated for testing consumer preference and/or acceptability in the 1940s, at the Food Research Division of the Quartermaster Food and Container Institute in Chicago, USA. "The hedonic scale assumes that consumer preference exists on a continuum and that preference can be categorised by responses based on like and dislike" (Peryam & Girardot, 1952). The samples can be presented to the consumers monadically (one at a time); alternatively the range of samples can all be placed on a tray and the panellist instructed to score each sample for degree of liking on the nine-point hedonic scale (Lawless & Heymann, 2010). Consumer preference can be determined by tasting the products blind (without any visual product information); however, consumer preference can also be tested with added information about the product. According to Tomlins *et al*. (2007), acceptability testing can be used for testing consumer acceptability of rice; however, they suggested that, in addition to the latter, affordability and the market price of rice should also be tested.

Hedonic scale data sets are usually analysed using parametric statistics, such as ANOVA, to determine whether samples differ significantly with regard to consumer preference. Hedonic data can also be coupled with sensory (obtained via extensive descriptive sensory analyses) or instrumental data (obtained via instrumental analyses such as instrumental texture profiling, GC or HPLC analyses) to ultimately determine the quality divers of consumer liking (Lawless & Heymann, 2010). For this, regression methodologies are often used, i.e. sophisticated multivariate techniques that relate consumer preference to product characteristics, primarily to understand the key sensory attributes that drive consumer preference (Lawless & Heymann, 2010). These methodologies constitute a group of statistical techniques that analyse preference data, by taking individual differences in consumers' preferences into account. In these techniques a limited number of products ($N_{products}$) are described by two sets of variables, i.e. 1) consumer preference (X) defined by $N_{individuals}$ respondents and 2) $N_{product\ descriptors}$ sensory (Y_1) measurements. A bi-linear modelling method, e.g. principal component regression (PCR) or partial least squares regression (PLSR) is used for extracting the main patterns of relationship between these two data tables, *X* and Y. When the $N_{products}$X$N_{individuals}$ preference table is used as *Y* and the $N_{products}$X$N_{product\ descriptors}$ instrumental and sensory table used as *X*, this is known as “external preference mapping”. Internal preference mapping refers to the analysis of preference directions and the associated consumer segments. Information about the sensory properties driving preference can be obtained by projecting sensory attributes onto the sample map, spanned by the key internal preference dimensions (Næs *et al.,* 2010). In PCA, the dimensionality of a data structure is reduced to a two-dimensional data bi-plot that simplifies the visualisation of a complex data structure. The first principal component (PC1) lies along the direction of maximum variance, which explains the largest part of the variability in the data. Higher-order PC directions usually explain small differences in the data, relating to stochastic noise. Elimination of the higher-order PC directions enables the researcher to identify the sensory attributes that explain the largest part of the variation in the preference data, i.e. to identify the most important drivers of consumers’ preference (Esbensen, 2006; Næs *et al.,* 2010).

In view of the above, the first aim of this investigation was to determine South African consumers’ preference for premium long-grain parboiled rice, using hedonic tests. A secondary aim was to determine the sensory drivers of consumer preference, using advanced regression analysis techniques. The third aim was to determine whether there is a trade-off between the various general quality drivers as perceived by consumers, using the focus group technique.

2. Materials and methods

2.1 Sample set for consumer analyses

Twelve premium long-grain parboiled rice samples (raw and cooked) were tested for sensory attributes in Chapter 3. As indicated in Chapter 3, eight of the set of 12 samples, illustrating the maximum variance, were chosen to be tested for consumer preference and consumer perception. Refer to Table 1 for the list of samples, as well as their countries of origin.

2.2 Consumer recruitment and screening

The recruitment of the consumers was conducted by a market research company (Consumers in Focus, Johannesburg, South Africa). Clear screening criteria were given, against which they had to screen the consumers. All consumers sourced had to be female, and had to be the main buyers and cooks of rice in their households. All the females had to be between the ages of 25-55 years and from the Living Standards Measure (LSM) group 6-10 (Anon., 2012). Three different geographical regions (Gauteng, Western Cape, and KwaZulu-Natal Provinces) were identified where the consumer preference analysis was to be conducted and designated ethnic groups were sourced. Other important criteria, used in the screening of consumers, were their proficiency in the English language, as it was important that they could convey their opinion both in written as well as verbal format. They also needed to consume rice at least two to three times per week to qualify and needed to purchase one of the following brands most often: Spekko, Tastic, Tasia or Aunt Caroline (all regarded as premium long-grain parboiled rice brands).

2.3 Design of consumer interfaces

Consumer interfaces were used to obtain both quantitative and qualitative consumer preference information. The former was obtained by using the nine-point hedonic scale, which was individually completed by each consumer taking part in the study. See Addendum 3 for the questionnaire for testing consumer liking of both the raw and cooked rice.

Following the completion of the nine-point hedonic scale, the qualitative study commenced. Focus group sessions were conducted to obtain a better understanding of the hedonic scale information, and also to gain insight on consumer opinions, perceptions and expectations about long-grain parboiled rice (refer to Addendum 3 for the topic guide).

Each focus group session was conducted in a two-hour period. The first hour was used to evaluate the blind liking of the cooked rice samples. These samples were presented to the consumers in two sets, with each set containing four of the cooked long-grain parboiled rice samples. Once the hedonic scale investigation was completed, a brief discussion followed. The second hour was used to evaluate the eight raw rice samples. The raw samples were also presented in two sets, with each set containing four samples. Following this, there was a brief discussion of the samples and some additional questions regarding consumer expectations, general ideas and attitudes about rice. Once the sessions were completed, the participants were rewarded with a fruit juice and then received their monetary incentive.

2.4 Sample preparation

The samples were prepared as described in Chapter 3. Approximately 50 g raw long-grain parboiled rice of each product was placed in large Petri dishes. The samples were each assigned a random three-digit code. The first set of cooked rice was placed in the glass ramekins, which were immediately presented to the consumers. The second set of cooked rice samples was also presented immediately to the consumers, or alternatively stored in bain-maries filled with boiling water; the bain-maries were then placed into an industrial thermo-fan oven (Hobart CSD 1012) set at 70°C and covered with aluminium foil, until required. The aim was, however, to avoid the oven heating step as far as possible, primarily to prevent sample moisture loss, but also to serve the samples directly after completion of the cooking phase.

2.5 Statistical procedures

Analysis of variance (ANOVA) tested whether the samples differed significantly ($p \leq 0.05$) regarding the respective liking attributes (SAS®, Version 9; SAS® Institute Inc., Cary, USA). Principal component analysis was conducted using XLStat (Version 2012.4.03, Addinsoft, SARL, Paris, France), to visualise and explain the consumer preferences for both raw and cooked samples. Partial least squares regression was then conducted using XLStat, to relate consumer preference (x-matrix) to the descriptive sensory analysis profiles (y-matrix) of the rice samples (Version 2012.4.03, Addinsoft, Paris, France), primarily to indicate sensory drivers of consumer liking.

3. Results and discussion

To investigate potential socio-demographic consumer segmentation, within the premium long-grain parboiled rice category, was not part of the scope of this investigation and will not be discussed, primarily because extensive degree of liking testing was not performed, using a large number of consumers.

Twenty consumers were sourced from three geographical areas, i.e. Western Cape, Gauteng and KwaZulu-Natal. The full sample set (n = 60), consisted mainly of consumers in the age group 25-35 (Table 2), which accounted for almost half (47.1%) of the consumers. The LSM group 10 represented 34.3% of the consumers in this study, followed by LSM 7 with 27.1% (Table 3). The majority of the consumers in this study (Table 4) purchased Tastic (47.1%), followed by Spekko (34.3%) and lastly AC (17.1%). The reason for the low AC representation was due to the fact that this brand is only available in the KwaZulu-Natal region. Sales volumes for May 2013 to May 2014 were 60 686.7, 35 457.2 and 2 4471.9 tons for Tastic, AC and Spekko respectively, within national retail in South Africa (Aztek data, 2014).

3.1 Quantitative data

The PCA bi-plot (Fig. 1) indicates the association between the eight rice samples and the liking attributes tested for the raw, as well as the cooked products. The first two principal components (Factor 1 and 2) explained most of the variability in consumer preference for both raw and cooked rice samples (98.5%). It can be seen in this PCA plot that there is a definitive preference for the raw and cooked attributes (Fig. 1) associated with the samples Vietn, Tasia and AM.

3.1.1 Liking attributes associated with the raw rice samples

The consumers analysed the raw samples for degree of liking of the appearance, aroma and overall quality. Analysis of variance results for raw appearance and raw aroma indicated that Vietn, AM and Tasia were most preferred, when evaluated for these specific liking attributes (Fig. 2a and b). These samples had means of 7.3, 6.8, 6.7, respectively, for raw appearance liking, and 7.2, 6.6, 6.6, respectively, for liking of raw aroma. These means translate back to the hedonic term "Like moderately". Although the liking values for the latter three samples are reasonably high, as depicted in Fig. 2a and b, it can be seen that there was a significant ($p \leq 0.05$) difference between Vietn and Tasia, with Tasia being slightly less liked than Vietn for raw appearance and raw aroma ($p \leq 0.05$). Spekko had a mean of 5.35 for liking of raw appearance and 5.0 for liking of aroma, which translates back to "Neither like nor dislike" in hedonic terms.

The liking means for raw overall indicated Vietn (7.5) as most preferred, with AM (7.21), Tasia (7.10) and Tastic being equally preferred for overall raw quality (Fig. 2c). Spekko had a mean of 5.63 for liking of overall quality, indicating that there was slight overall degree of liking for Tastic's raw appearance, aroma and overall quality.

Partial least squares regression was conducted on the consumer hedonic data and sensory profiling data. The PLS plot (Fig. 3) shows that the consumers clearly preferred the raw samples of Vietn and Tasia, with "whiteness intensity" being the main driver of consumer liking when considering the raw product. Investigation of the correlation matrix indicated that "whiteness intensity" influenced consumer liking of raw rice appearance ($r = 0.842$) and raw rice overall ($r = 0.840$). Research conducted by Goodwin *et al*. (1992) and Suwansri *et al.* (2002) found that consumers prefer raw and cooked rice with high "whiteness intensity".

Results for the standardised coefficients of the descriptors similarly showed for liking of raw appearance (Fig. 4a), that "whiteness intensity", "oily aroma" and "crushed maize kernel aroma" had the highest degree of influence over the dependent variable raw appearance liking. Similarly, for liking of raw aroma (Fig. 4b) and liking of raw overall quality (Fig.4c), these descriptors had the highest degree of influence over the dependent variable raw aroma liking and liking of raw overall quality, respectively.

3.1.2 Liking attributes associated with the cooked rice samples

According to the ANOVA results, liking of the cooked appearance, as well as the cooked aroma and flavour (Fig. 5a and b), were both significantly ($p \leq 0.05$) higher for Vietn and Tasia. The mean scores for these products were approximately seven or more, indicating a high degree of liking for cooked appearance and flavour of these two samples.

The mean liking values for cooked texture indicated that Vietn was most preferred (mean value of 7.2), followed by Tasia (mean value of 6.9) and AM (mean value of 6.3) (Fig. 5c), with AM being significantly ($p \leq 0.05$) less preferred than Vietn for texture. Spekko had an average mean of

4.5, which translates into “Neither like nor dislike”. Overall liking of the cooked product (Fig. 5d) indicated that Vietn (7.4) and Tasia (6.96) were liked best, followed by AM (6.81). These three rice products were equally and highly liked for overall eating quality.

The PLS plot (Fig. 6) indicated that the consumers clearly preferred Tasia and Vietn for all the liking attributes tested. On the right side of the PLS plot it seems that “whiteness intensity” and some of the textural attributes drive consumer preference. Research done by Okabe (1979) and Rousset *et al*. (1999) found that consumers consider the texture of cooked rice to be its key quality attribute and when it comes to appearance, many consumers prefer raw and cooked rice with a high degree of whiteness (Goodwin *et al*., 1992; Suwansri, 2002).

The standardised coefficients for liking of cooked appearance (Fig. 7a) showed that “stickiness in mouth”, “maize porridge aroma”, “whiteness intensity”, “grain-to-grain stickiness”, “starchy after 5 chews” and “swollen/plump” had the highest degree of influence over the dependent variable cooked appearance liking. The correlation matrix indicated that “whiteness intensity” (r = 0.809), “grain-to-grain stickiness” (r = 0.683) and “swollen plump” (r = 0.827) positively influenced consumer liking of cooked rice appearance.

Similarly, the standardised coefficients of descriptors for liking of cooked aroma and flavour (Fig. 7b) showed “maize porridge aroma”, “stickiness in mouth”, “whiteness intensity”, “grain-to-grain stickiness”, “starchy after 5 chews” and “swollen plump” had the highest degree of influence over the dependent variable cooked aroma and flavour liking. The correlation matrix indicated that there were no aroma or flavour attributes that influence consumer liking of cooked rice aroma and flavour.

When considering the standardised coefficients for cooked texture (Fig. 7c), it was evident that “maize porridge aroma”, “stickiness in mouth”, “whiteness intensity”, “grain-to-grain stickiness”, “starchy after 5 chews” and “swollen/plump” influenced the dependent variable cooked texture the most. The correlation matrix indicated that “stickiness in mouth”, (r = 0.929), “swollen/plump” (r = 0.778) “starchy after 5 chews” (r = 0.764) and “grain-to-grain stickiness” (r = 0.715) positively influenced consumer liking of cooked rice appearance.

The standardised coefficients for overall liking of the cooked product (Fig. 7d) showed that “maize porridge aroma”, “stickiness in mouth”, “whiteness intensity”, “grain-to-grain stickiness”, “starchy after 5 chews”, “swollen/plump” and “buttery aroma” had the biggest influence over the dependent variable cooked overall liking. The correlation matrix also indicated that “stickiness in mouth”, (r = 0.921), “whiteness intensity” (r = 0.737) and “starchy after 5 chews” (r = 0.733), “swollen plump” (r = 0.730) and “grain-to-grain stickiness” (0.652) positively influenced consumer liking of cooked rice texture.

On both the raw and cooked attributes results it was thus evident that Vietn, Tasia and AM were the most preferred long-grain parboiled rice brands. As indicated in Fig. 3, the drivers of consumer liking for raw parboiled rice was mostly appearance, with "whiteness intensity" having the biggest influence. Similarly, it was clear that the drivers of liking of the cooked product are appearance and texture (Fig. 6). "Whiteness intensity" was the sensory driver influencing appearance liking, while texture was influenced by the sensory attributes "stickiness in mouth", "swollen/plump", "starchy after 5 chews" and "grain-to-grain stickiness".

3.2 Qualitative data

Table 5 indicates the topic guide that was used during the interaction with the consumers in the focus group sessions. The expectations, as well as the general perceptions that consumers have of long-grain parboiled rice, were probed.

3.2.1 Expectations on long-grain parboiled rice

What comes to mind if you think of rice?

The focus here was to investigate the consumer's ideas and thoughts on rice, assuming that certain aspects mentioned here will be at the front of the consumer's mind, when she is considering purchasing rice in a supermarket. The participants of the focus groups had many associations with rice, from rice being a staple food, to the type of meals that they will prepare, when using rice as one of the main ingredients. The following important product characteristics were also highlighted for both raw and cooked rice. Raw rice should be "unbroken", "kernel length" was important, as well as the "colour" of rice. Cooked rice should be "fluffy", "white in colour" and it should also be "soft, yet firm". Some participants indicated a strong association with specific brands, such as Spekko and Tastic.

What is your expectation of raw rice? Indicate important raw rice characteristics.

It was important to establish which raw rice characteristics consumers consider when evaluating raw rice, before making a purchase. They were further probed to describe their preferences on these characteristics. Two key factors were highlighted in terms of the raw rice: firstly, the longer the grain, the more "loose" the rice cooked and the shorter the grain, the more "sticky" the rice cooked; secondly, if the rice was more "yellow" in colour, the more loose it would tend to cook. Other raw rice characteristics included that the rice had to be "clean", with no stones or any other foreign objects present or any visual impurities visible on the rice kernel. The visual appearance of the rice was important; it had to be "bright and light" and a package of rice should contain mostly "whole kernels". The rice had to be of "even tone" and the colour "white" and "light". Other factors that were considered by consumers purchasing raw rice was price, clear and easy to understand cooking instructions, and the expiry date legible. Lastly, most consumers considered the brand as part of their purchase decision making.

What is your expectation of cooked rice? Indicate important cooked rice characteristics.

The focus was to gain an understanding of the cooked rice characteristics that consumers find important. The most recurring characteristics were that rice should be “white” and “loose”, and it should also have an appealing “aroma” and “flavour”.

Based on the above-mentioned findings on raw and cooked rice, having rice that was “light” and “white”, but that was also “loose and fluffy” when cooked, appeared to be an important procurement/processing consideration. The degree of whiteness on both raw and cooked rice is, thus, one of the most important quality attributes (Goodwin *et al*., 1992; Suwansri *et al*., 2002).

3.2.2 General perceptions on long-grain parboiled rice

Describe good quality rice

Most consumers referred to cooked rice quality attributes, which could indicate that cooked rice attributes are more important than those of raw rice. Good quality cooked rice was described as being “loose” and “fluffy” and “white” in colour. There should be as few as possible “broken” grains in the product, as this will cause the rice to become “stickier”. Furthermore, rice of a good quality has to be “clean” and “long grain”. The “texture” has to be “soft” yet “firm”, but “melt in the mouth” at the same time. The consumers also noted that the rice should have a pleasant “aroma” and that if it had a pleasant “flavour”, that is would be an “added bonus”, since rice is mostly bland and takes on the flavour of any added spices added or of other food that it is consumed with it.

Three brands were mentioned when describing good-quality rice: Tastic, Spekko and AC. For one group of consumers “how much rice you get once cooked” was also important.

Which brands do you buy the most and why?

Numerous brands were mentioned by the consumers. Some participants used AC**,** specifically for breyani and stir-fry, as the cooked rice will always be “firm and fluffy, will not cook too soft, and it can withstand overcooking”. Participants felt that AM “saves time because it’s quick cooking”. *Tasmahal* was liked for its long grain capacity. Some participants felt that Tastic “does not give problems”; and was “reliable and easy to cook”. Some consumers indicated that their mothers cooked Tastic while they were growing up, and they felt that it always worked. Tastic was “versatile”; this brand could be cooked both in the microwave oven and on the stove. They felt that you could not mess Tastic up and you always knew what you were going to get. It also had “loose kernels” which were “white, fluffy and quick cooking”. It was clear that the focus group consumers knew the Tastic brand: good appearance, good yield, but for some affordable only when on "promotion". Participants described *Allsome* as being "white, fluffy and can be used for everything".

The following three brands, Spekko, AC and Tastic, were mentioned together by a number of consumers; these brands were mainly "used out of tradition" (passed on by generations); it was trusted, because it cooked well. These brands of rice were "white and fluffy". Spekko was indicated as having "long kernels" which were "loose"; it "always cooks well" and "tastes good" and was affordable. It was "soft but not sticky", had a "good colour" and "flavour", and you also got a lot of cooked rice from Spekko (high-yielding rice). Generally the consumers approached the *No name brands* on a "trial and error" basis, until they found something that met their expectations.

How important is the brand when purchasing rice?

Brand identification is an important precursor of brand loyalty and subsequently plays a pivotal role in the consumers' brand choice and purchasing behaviour (Ahearne *et al*., 2005). The rice brand "gives a sense of reliability" and the familiarity and trust placed in brands have been "passed on through generations". Brand-loyal consumers said "you know what you are going to get when you buy Tastic"; if money was tight, they "will rather buy a small packet of Tastic than a lesser known, cheaper brand". Some consumers indicated that they would buy "another brand" if their preferred brand was not available, whilst others would also consider price and look out for promotions before they bought. Other consumers, however, indicated that they "are not prepared to take the chance on cheaper brands"; the brand symbolised quality and "in the end you save money because it is good quality".

What price/kg are you willing to pay for your ideal brand of rice?

The focus of this question was to determine the trade-off between expected quality, which we termed "ideal rice", and "price". Some participants indicated that the rice must be "on promotion" for them to be willing to try it. They felt that their ideal rice had to be "on par" with what rice currently sold for (R12-R15/kg). Other consumers indicated that they were prepared to pay "R100/10kg" or "R70-80/10kg". One group of consumers felt that their "lifestyle has changed, health has become more important". Their available time had become less and that they had budget constraints. However, this group of consumers still wanted to "give the best they can afford to their families" and they were willing to pay R45-R50/5kg. Some consumers indicated that they were not willing to pay an "exuberant" price, as rice was only a side dish in a meal and were prepared to pay "R16-R20/2kg" whilst others felt that "R23/2kg" was the most that they were willing to pay, not more than a R3 increase. This increase in price per kg was slightly more than what long-grain parboiled rice currently sold for (R12-R15/kg). Aztek data (2014) for national retail in South Africa indicates that for both Spekko and Tastic the 2 kg format is most frequently sold, while for AC, the 10 kg format is the most popular, followed by the 5 kg and then the 2 kg formats.

Rank the most important cooked rice characteristics.

The aim of this question was to determine if there was a trade-off between the various identified rice characteristics. Some consumers ranked texture as the most important characteristic, followed by flavour and aroma, and lastly both colour and “looseness”. Other consumers placed flavour as the most important characteristic followed by “fluffiness and looseness”, and lastly, yield and “firmness”. Some placed yield as the most important characteristic, followed by flavour and “plumpness”, “fluffiness”, having a typical rice aroma, and being white and loose. Lastly, some consumers placed flavour as the most important characteristic, followed by “whiteness and looseness, fluffiness and plumpness”. These results indicated that different ethnic groups viewed different quality drivers as important. Although the order of the characteristics had been indicated as different for different consumers, the characteristics mentioned as important were similar, indicating that these characteristics should be seen as equally important, when quality improvements were made through either better procurement or processing. Although rice consumers have strong preferences for specific sensory attributes, it is important to note that a range of preferences can exist within a country (Bett-Garber *et al*., 2012). When considering the most important cooked rice characteristics mentioned above, ethnicity had a greater influence on preference and subsequent trade-off, than LSM or demographic area.

Conclusions

This study provided important insights into the preference for long-grain parboiled rice, the main drivers associated with quality rice, as well as the trade-off between different drivers, based on research conducted with South African consumers.

The participants in this consumer study clearly indicated a preference for both raw and cooked Vietn, Tasia and AM. To get a better understanding of what drived their preference for raw quality it was determined that the appearance and colour attributes were the main drivers, with specifically “whiteness intensity” significantly ($p \leq 0.05$) influencing consumer liking for raw rice. The preference for cooked rice was driven by appearance, colour and texture. The “whiteness intensity”, “grain-to-grain stickiness” and “swollen/plump” significantly ($p \leq 0.05$) influenced consumer liking for appearance, while “stickiness in mouth”, “swollen/plump”, “starchy after 5 chews” and “grain-to-grain stickiness” significantly ($p \leq 0.05$) influenced consumer liking for texture. Vietn, Tasia and AM clearly out-performed the other rice samples on these key quality drivers. The participants in this study indicated that cooked rice properties were more important than raw rice properties.

Additional to the quality drivers, it was indicated that the raw rice had to be uniform in terms of appearance (colour and grain size); the rice also had to be clean and free from any dark spots. The grains were preferred to be unbroken and long, as this would influence the way the rice cooked, in terms of grain-to-grain stickiness and final product yield. The colour of the raw rice was preferred as white, but should not be unnaturally white. The quality divers for cooked rice were texture of the cooked rice, as well as the visual appearance. The rice needed to be white, as well as loose and fluffy; the texture should be firm yet soft, but not sticky. The rice should be plump, which is indicative of a good yield.

When considering the trade-off between the main drivers of quality, it was evident that different groups of consumers valued different quality drivers. This consumer grouping is characterised by ethnicity rather than demographic area or LSM measures. Only drivers that are influenced by processing will be considered as these are the parameters that can be adjusted to facilitate the desired product outcome, including texture, looseness/fluffiness and colour.

Opportunities exist, based on the outcome of this study, to either source rice of a suitable quality or to facilitate processing of a suitable rice variety with the desired characteristics, based on the consumers’ preferences.

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Table 1 Samples used for testing of consumer liking and perceptions of long-grain parboiled rice as commercial product.

Country of origin	Conventional name	Abbreviation/name used in this study
North America	Riceland	RiceL
	Woolworths	WW
	Harvest Dawn	HDawn
Vietnam	Vietnam	Vietn
Thailand	Tasia	Tasia
	Spekko	Spekko
	Tastic	Tastic
South America	Americano	AM

Table 2 Age composition of focus groups in respective areas.

		25-30	31-35	36-40	41-45	46-50	51-55	TOTAL
JHB	count	7	4	1	2	2	4	20
	%	*35*	*20*	*5*	*10*	*10*	*20*	*28.6*
WC	count	5	8	6	4	3	4	30
	%	*16.7*	*26.7*	*20.0*	*13.3*	*10.0*	*13.3*	*42.9*
KZN	count	3	6	2	5	3	1	20
	%	*15*	*30*	*10*	*25*	*15*	*5*	*28.6*
TOTAL	count	15	18	9	11	8	9	70
	%	*21.4*	*25.7*	*12.9*	*15.7*	*11.4*	*12.9*	*100*

Table 3 LSM composition of focus groups in respective areas.

		6	7	8	9	10	TOTAL
JHB	count	0	4	2	5	9	20
	%	*0*	*20*	*10*	*25*	*45*	*100*
WC	count	2	12	6	4	6	30
	%	*6.7*	*40*	*20*	*13.3*	*20*	*100*
KZN	count	0	3	4	4	9	20
	%	*0*	*15*	*20*	*20*	*45*	*100*
TOTAL	count	2	19	12	13	24	70
	%	*2.9*	*27.1*	*17.1*	*18.6*	*34.3*	*100*

LSM = Living standards measure (Anon., 2012)

Table 4 Brands most often bought by focus groups in respective areas.

		Spekko	Tastic	Aunt Caroline	Tasia	TOTAL
JHB	count	4	16	0	0	20
	%	*20*	*80*	*0*	*0*	*100*
WC	count	18	12	0	0	30
	%	*60*	*40*	*0*	*0*	*100*
KZN	count	2	5	12	1	20
	%	*10*	*25*	*60*	*5*	*100*
TOTAL	count	24	33	12	1	70
	%	*34.3*	*47.1*	*17.1*	*1.4*	*100*

Table 5 Topic guide of expectations and perceptions tested during the focus group technique.

Expectations
1. What comes to mind first when you think of rice?
2. When selecting raw rice what characteristics/attributes are important? And why?
3. When eating cooked rice what characteristics/attributes are important? And why?
Perceptions
1. Describe a good quality rice
2. Rank the most important cooked rice characteristics
3. How important is brand?
4. Which brands do you buy the most and why?
5. What price/kg are you willing to pay for rice that meets all your expectations?

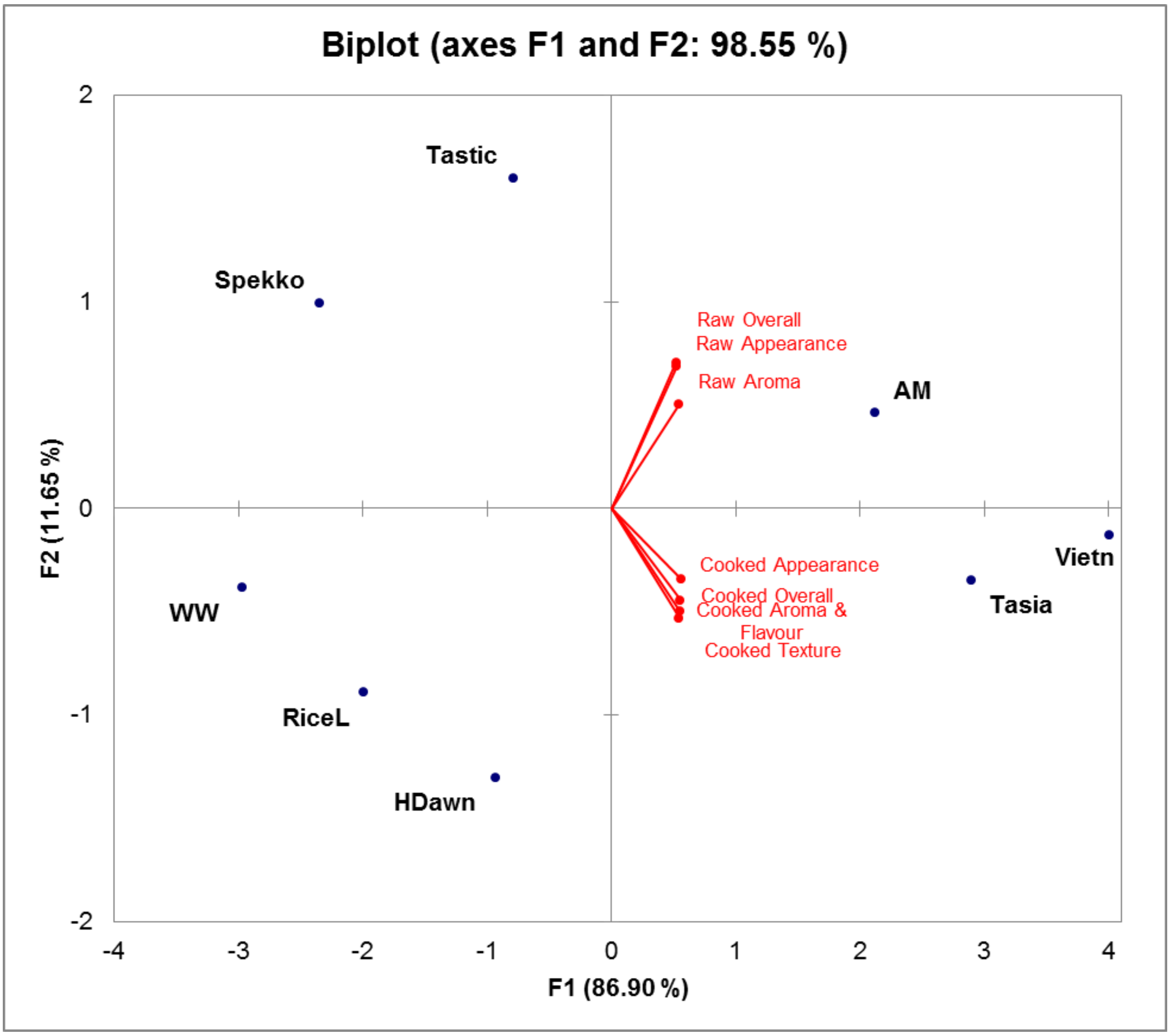


Fig. 1 PCA bi-plot indicating the eight long-grain parboiled rice samples and their association with the degree of liking attributes evaluated during the quantitative assessment using the hedonic scale.

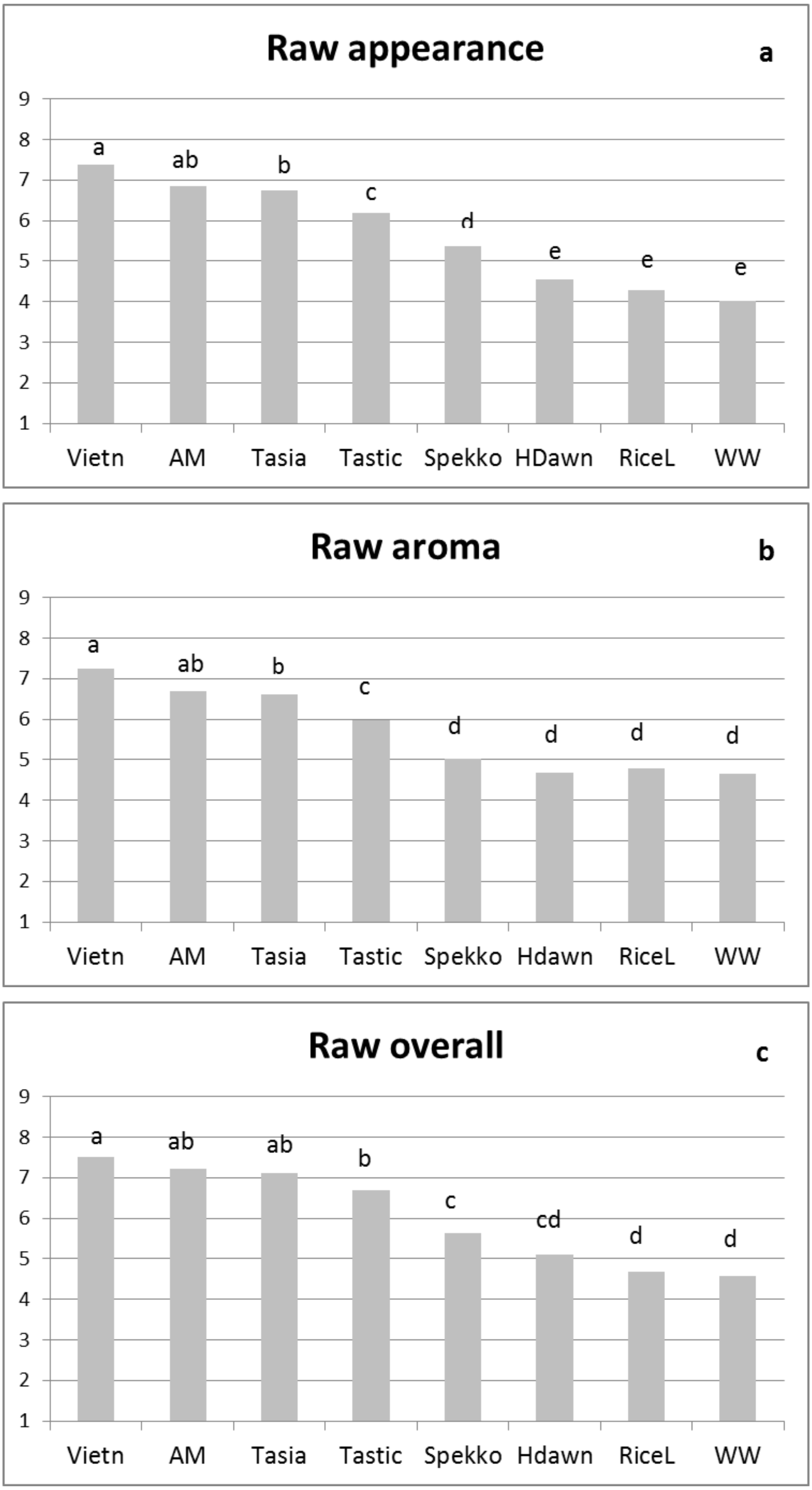


Fig. 2 Mean hedonic responses on raw product attributes for long-grain rice parboiled samples, i.e. **a)** Raw appearance, **b)** Raw aroma, **c)** Raw overall. Different alphabetical letters above each bar indicate significant differences between the samples ($p \leq 0.05$).

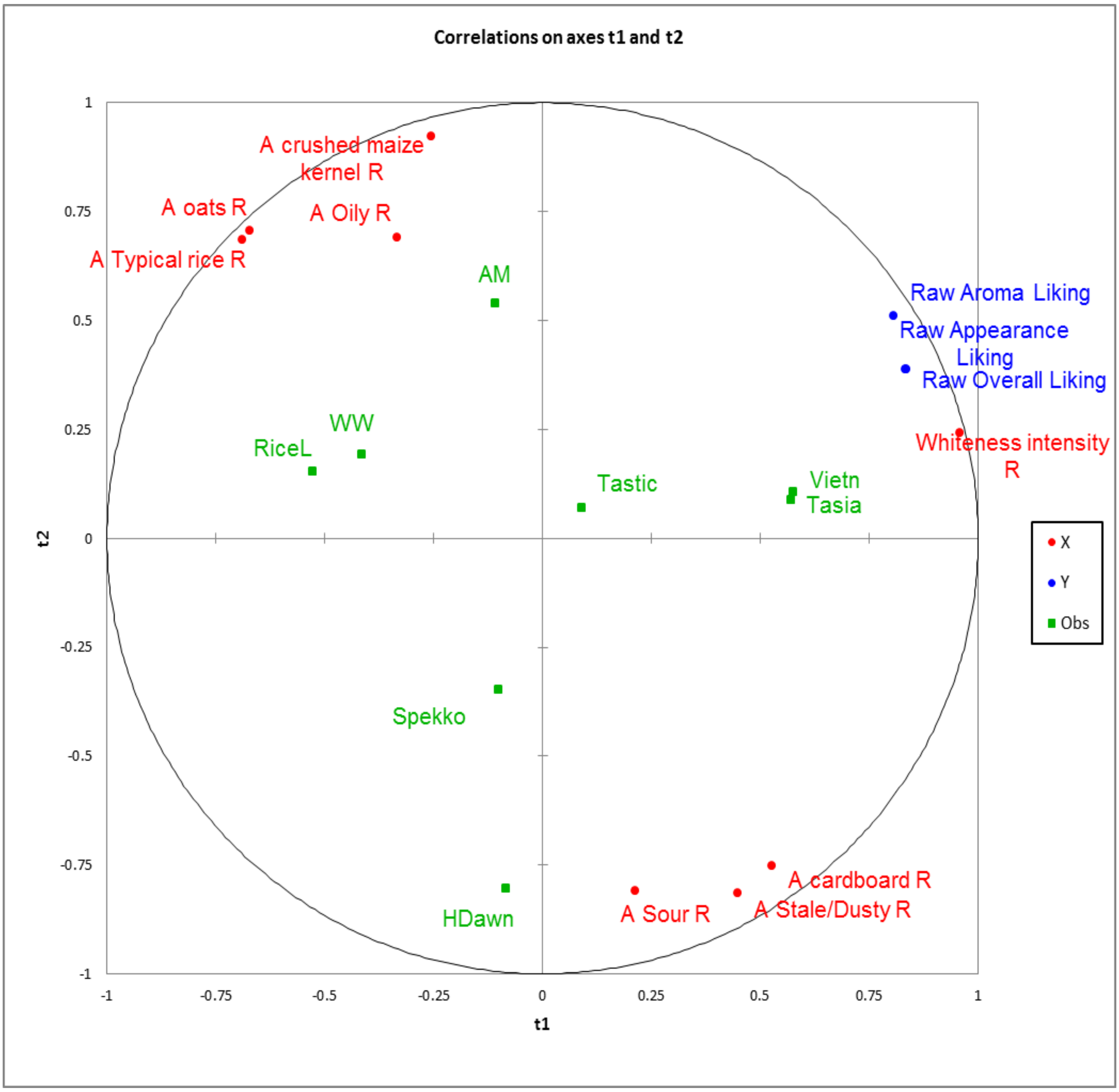
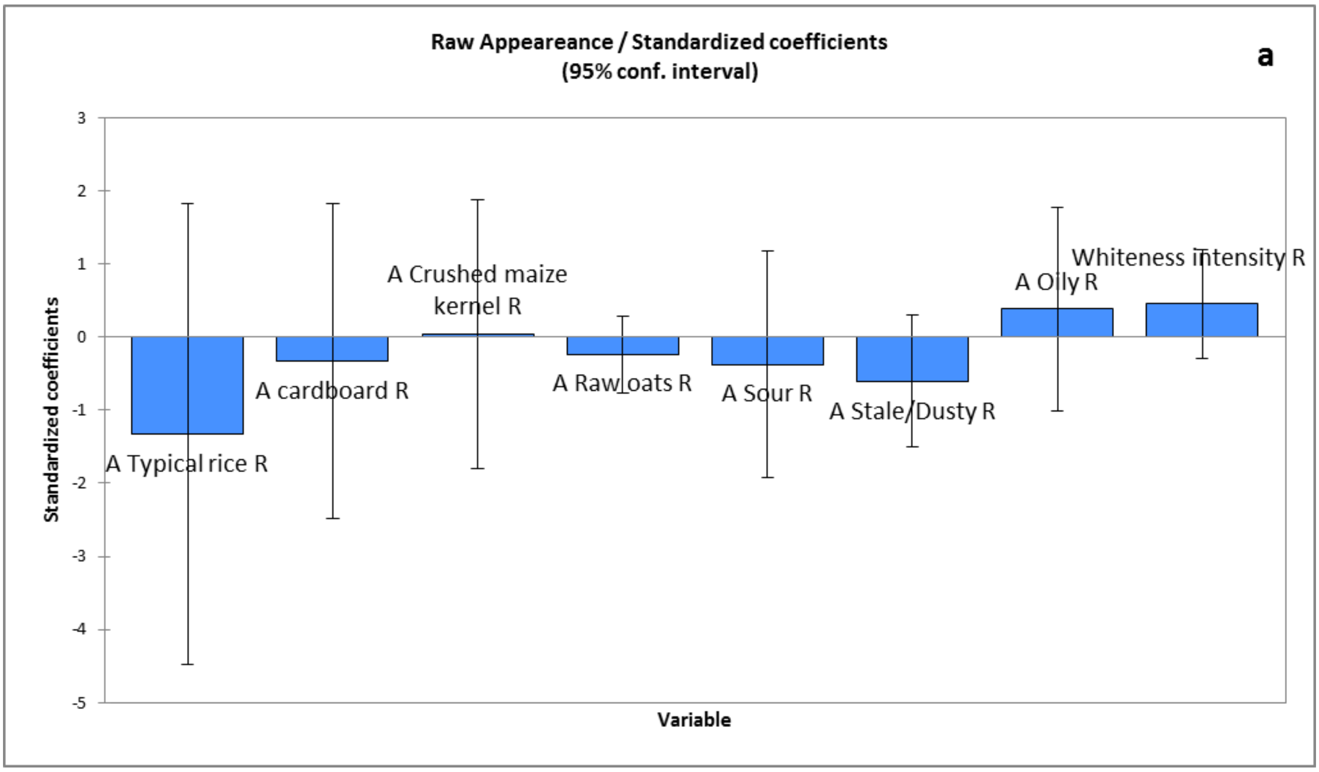
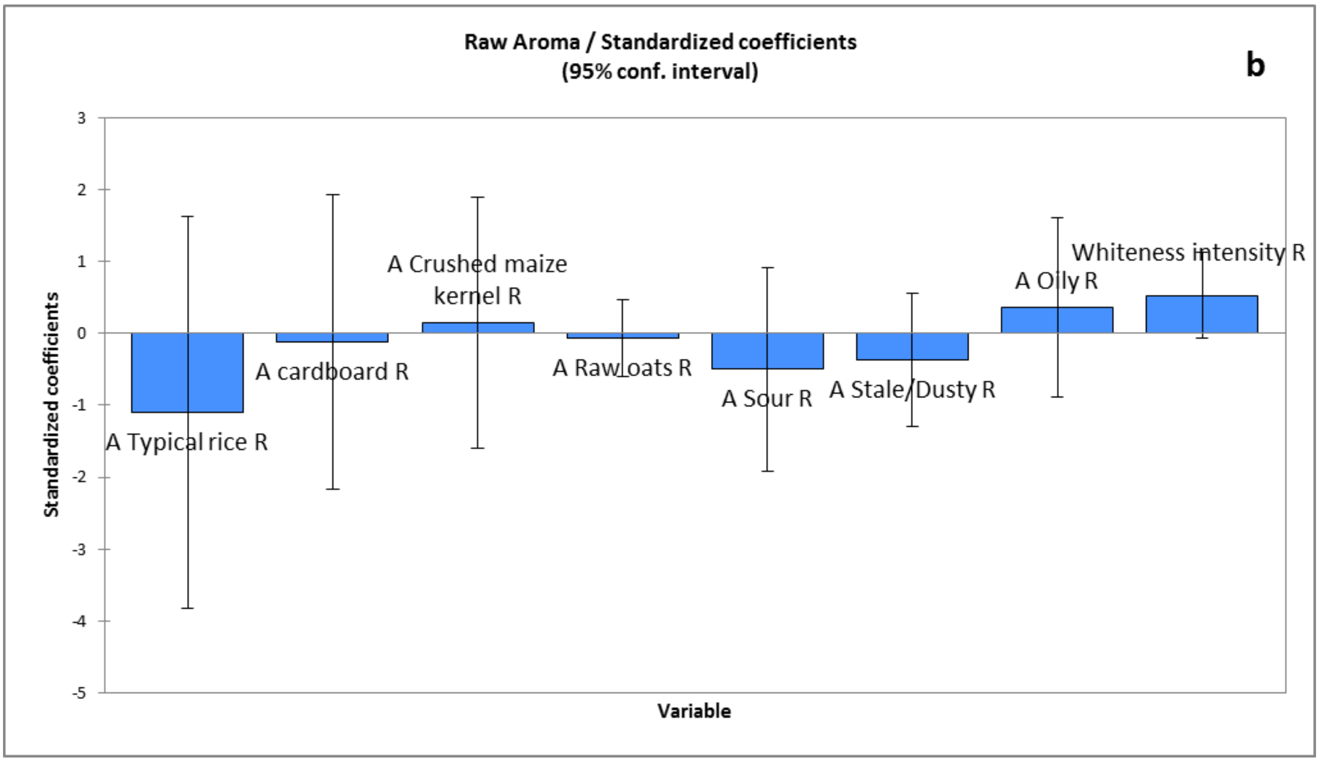


Fig. 3 Partial least squares regression (PLS) plot indicating consumer acceptance of raw rice **(Blue)** in relation to the 12 rice samples **(Green),** and selected sensory characteristics **(Red).** The letters "A" and "R refer to aroma and raw, respectively.



Raw Appeareance / Standardized coefficients
(95% conf. interval)
a
Standardized coefficients
3
2
1
0
-1
-2
-3
-4
-5
A Typical rice R
A cardboard R
A Crushed maize kernel R
A Raw oats R
A Sour R
A Stale/Dusty R
A Oily R
Whiteness intensity R
Variable



Raw Aroma / Standardized coefficients
(95% conf. interval)
b
Standardized coefficients
3
2
1
0
-1
-2
-3
-4
-5
A Typical rice R
A cardboard R
A Crushed maize kernel R
A Raw oats R
A Sour R
A Stale/Dusty R
A Oily R
Whiteness intensity R
Variable

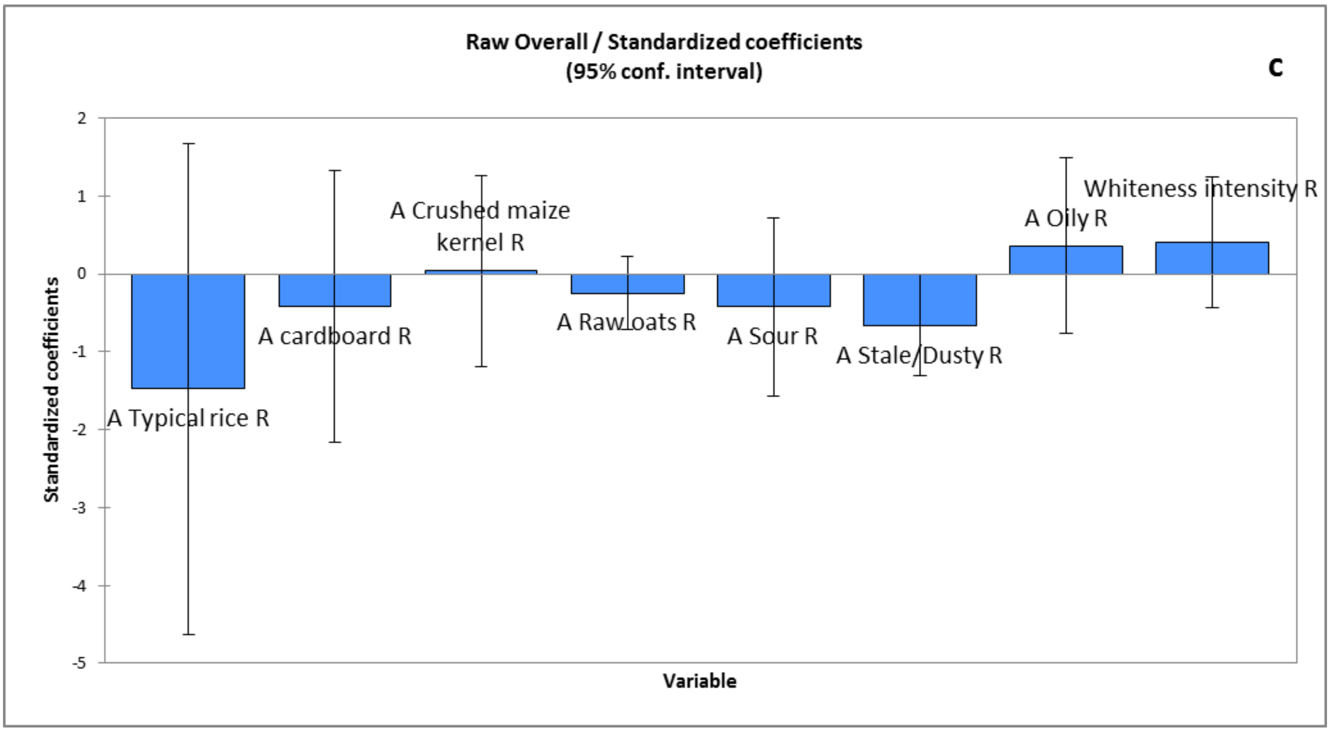


Fig. 4 Standardised coefficients at a confidence interval of 95%, performed on consumer data for **a)** Raw appearance, **b)** Raw aroma and **c)** Raw overall. The letters “A” and “R” refer to aroma and raw, respectively.

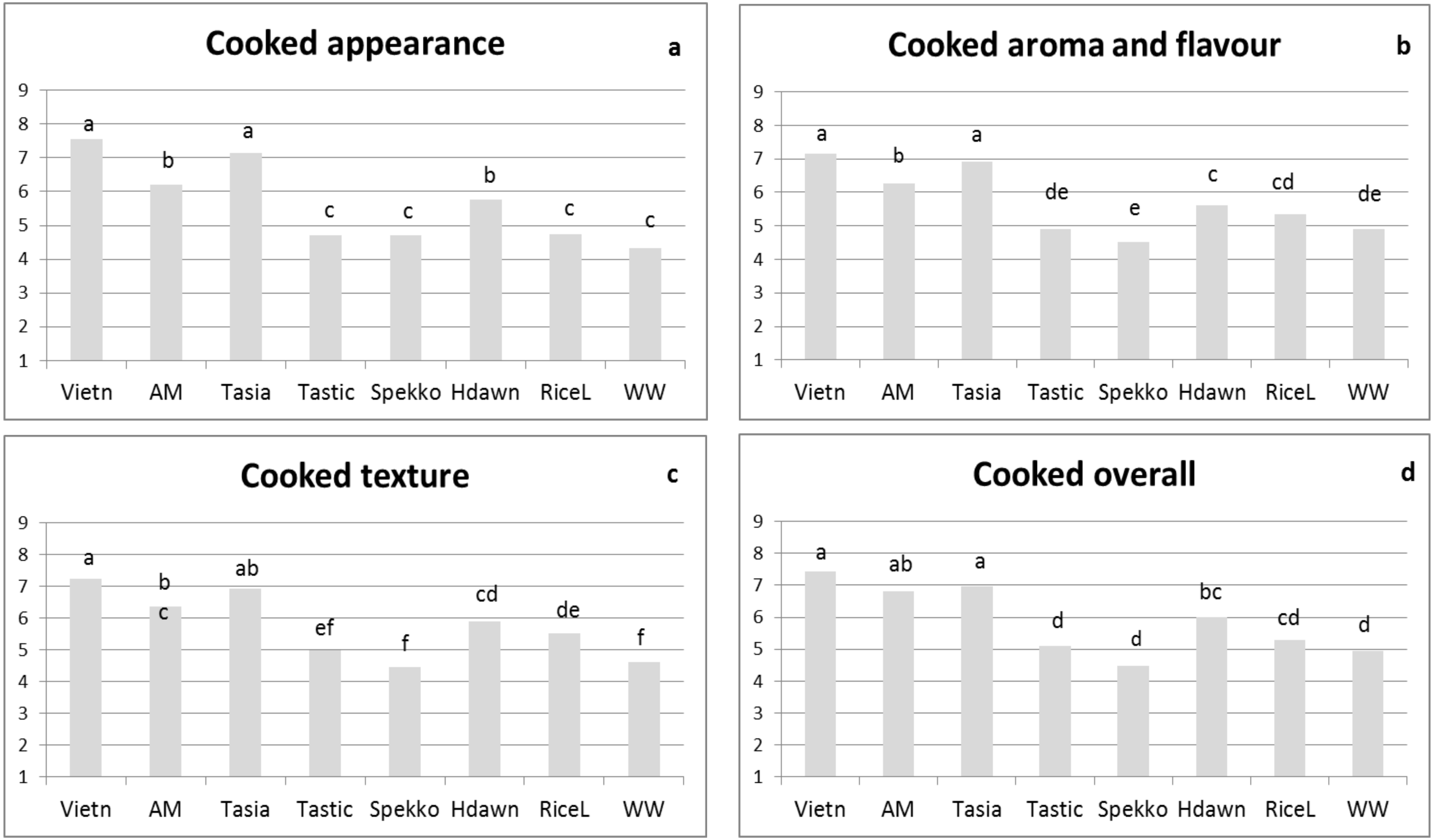


Fig. 5 Mean hedonic responses (scale 1-9) on cooked product attributes for long-grain parboiled rice, i.e. **a)** Cooked appearance, **b)** Cooked aroma and flavour, **c)** Cooked texture, **d)** Cooked overall. Alphabetical letters above each bar indicate the significant differences between the samples at $p \leq 0.05$.

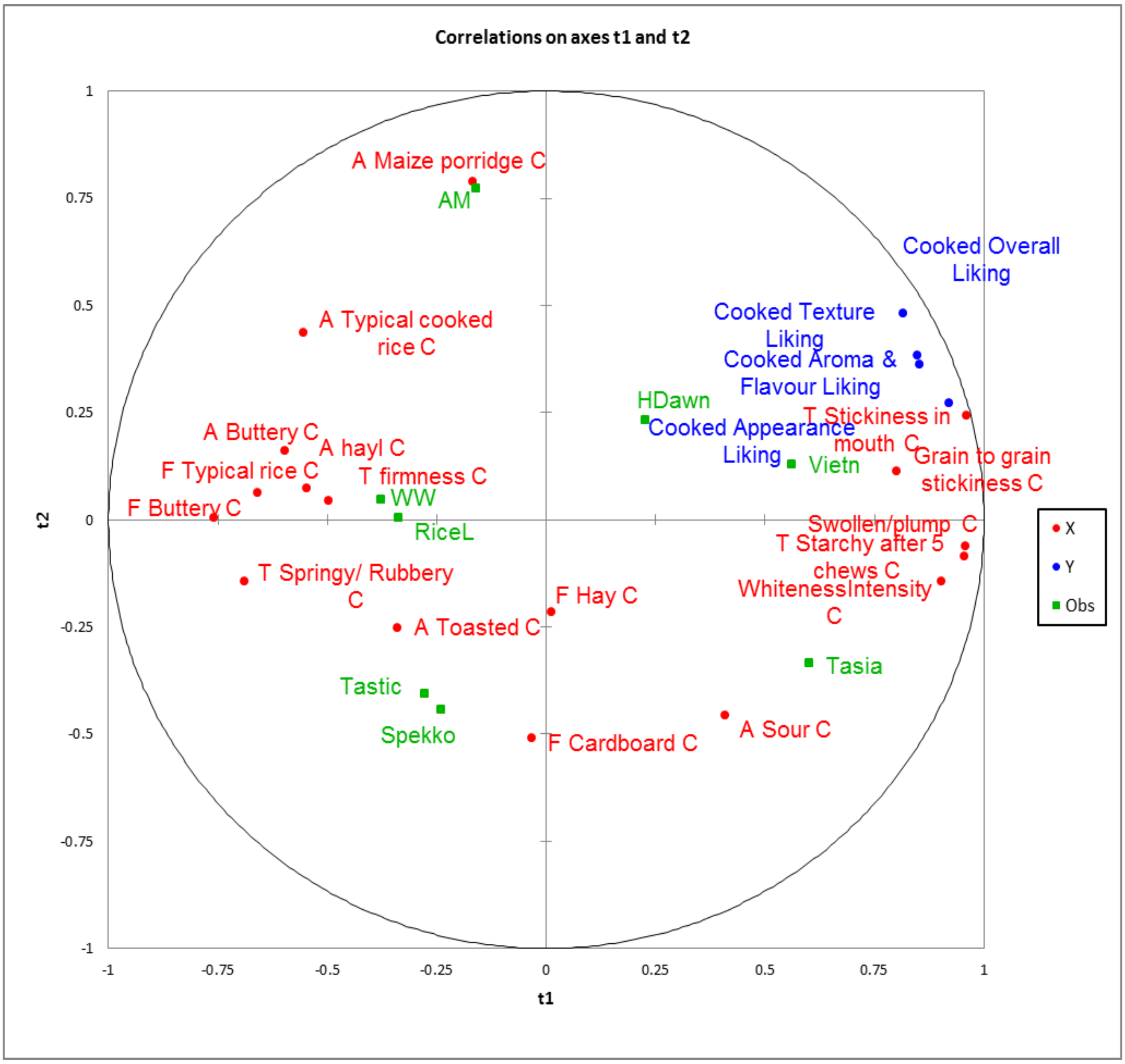
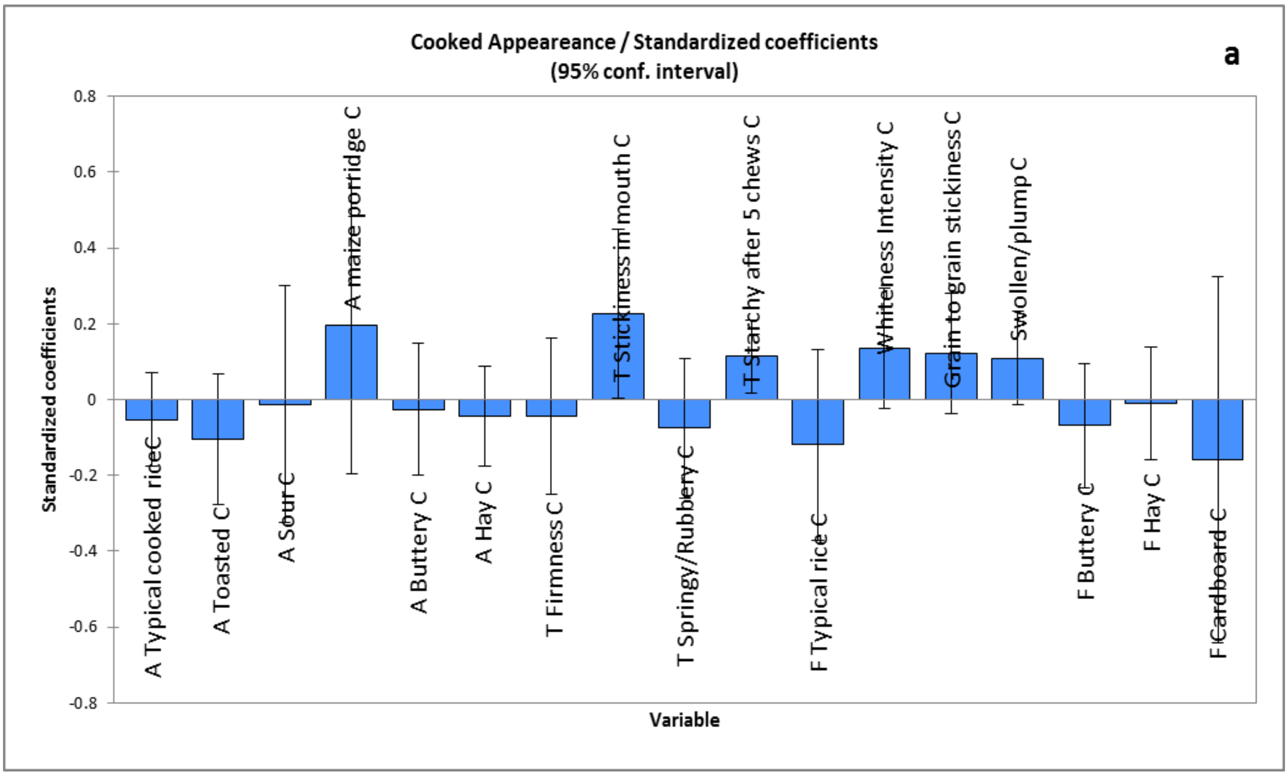
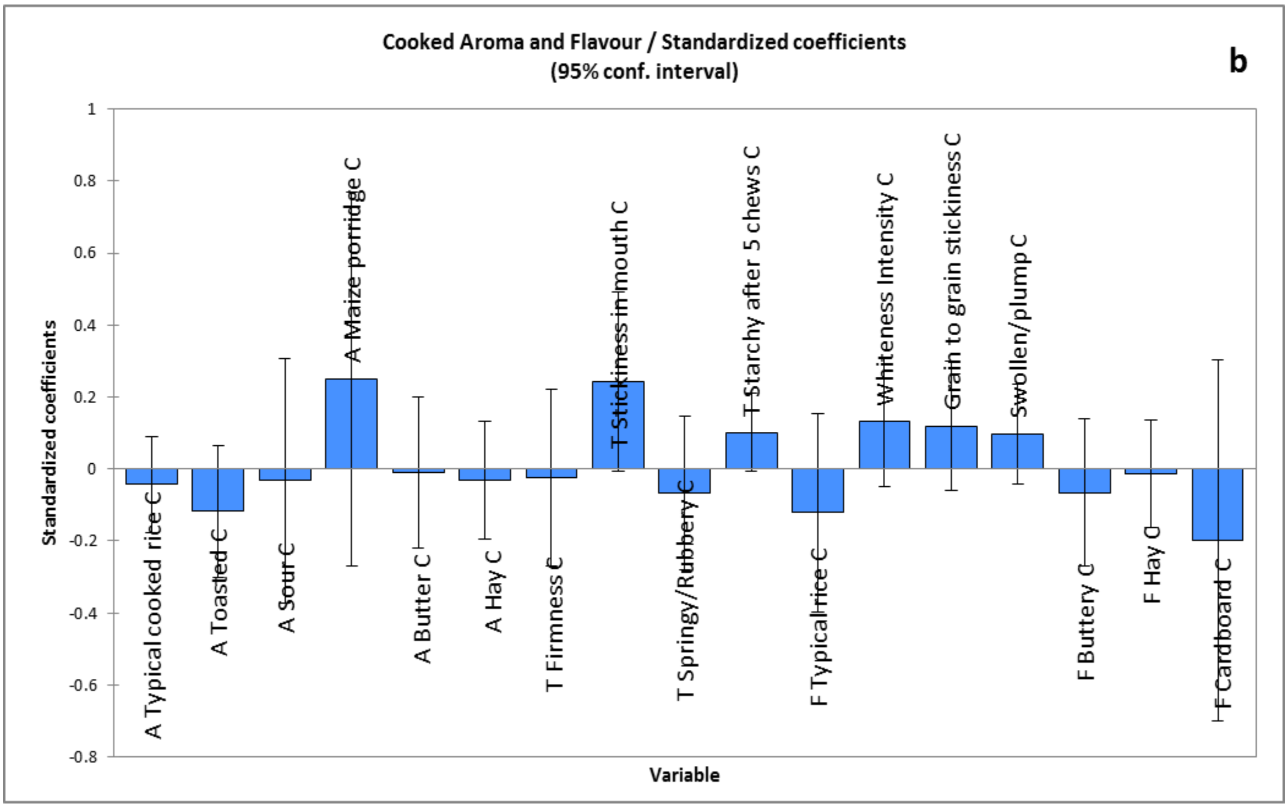


Fig. 6 PLS plot indicating consumer acceptance of cooked rice **(Blue)** in relation to the 12 rice samples **(Green),** and selected sensory characteristics **(Red).** The letters "A", "C" and "F" refer to aroma, cooked and flavour, respectively.


Cooked Appeareance / Standardized coefficients
(95% conf. interval)
a
Standardized coefficients
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
A Typical cooked rice C
A Toasted C
A Sour C
A maize porridge C
A Buttery C
A Hay C
T Firmness C
T Stickiness in mouth C
T Springy/Rubbery C
T Starchy after 5 chews C
F Typical rice C
Whiteness Intensity C
Grain to grain stickiness C
Swollen/plump C
F Buttery C
F Hay C
F Cardboard C
Variable


Cooked Aroma and Flavour / Standardized coefficients
(95% conf. interval)
b
Standardized coefficients
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
A Typical cooked rice C
A Toasted C
A Sour C
A Maize porridge C
A Butter C
A Hay C
T Firmness C
T Stickiness in mouth C
T Springy/Rubbery C
T Starchy after 5 chews C
F Typical rice C
Whiteness Intensity C
Grain to grain stickiness C
Swollen/plump C
F Buttery C
F Hay C
F Cardboard C
Variable

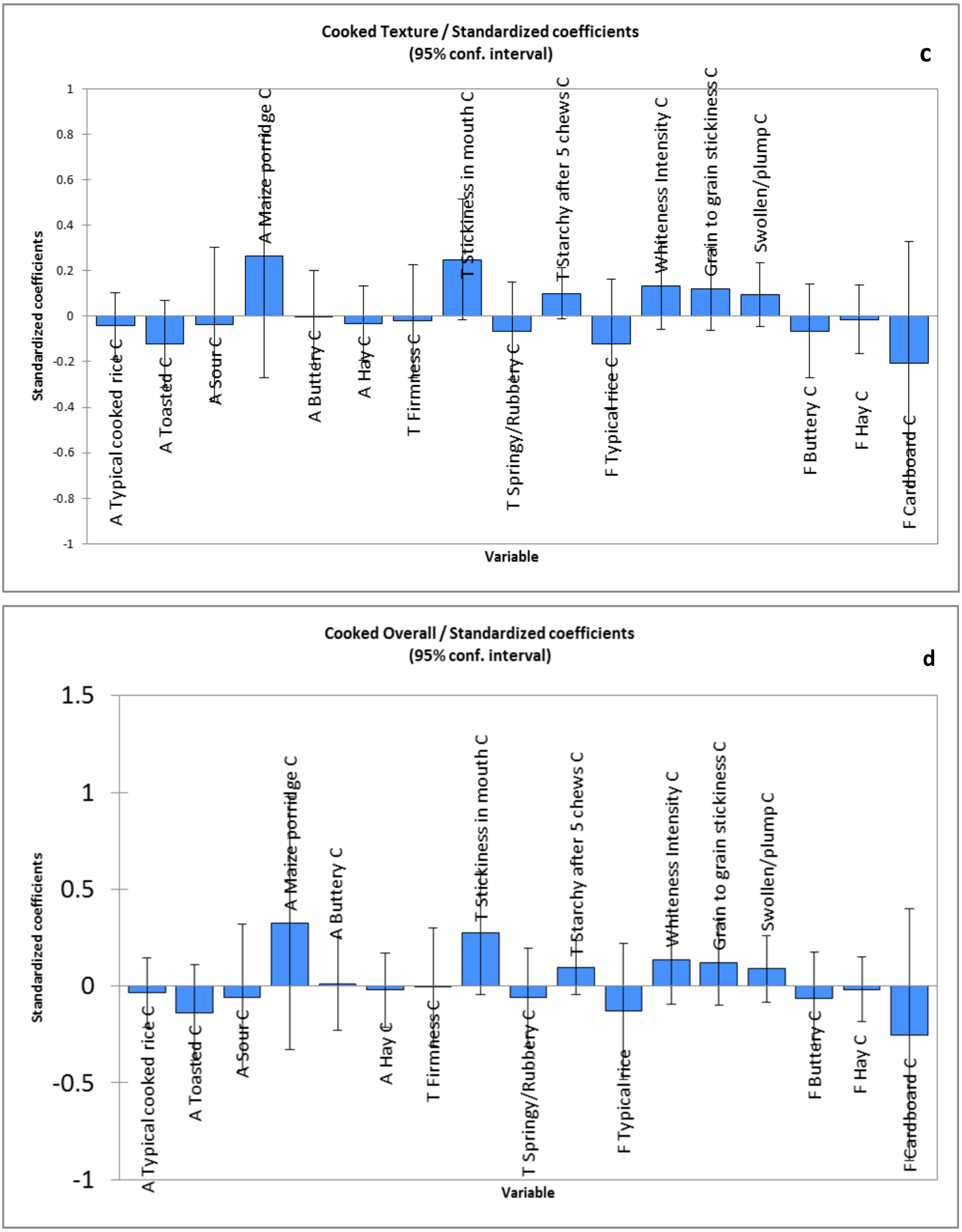


Fig. 7 Standardised coefficients at a confidence interval of 95%, performed on consumer data for **a)** Cooked appearance, **b)** Cooked aroma and flavour, **c)** Cooked texture and **d)** Cooked overall. The letters “A”, “C” and “F” refer to aroma, cooked and flavour, respectively.

Addendum 3 – Questionnaires for focus groups

Set 1

Four treatments of rice

5 Sept/18 & 19 Sept/23 Sept/26 & 27 Sept

Demographic info:

Please complete the following questions.

Name						
Contact details	Tel no (H)			Mobile		
Gender	Male			Female		
Indicate your age group	19-24	25-30	31-35	36-45	46-55	55+
How often do you consume rice?	Every day	Every second day	Once a week	Twice per month	Once a month	

- You have received four samples of rice; all samples are processed in the same way.
- Please evaluate the set of cooked rice in front of you and give a score for appearance, aroma and flavour, and texture as well as an overall eating score.
- Please evaluate the set of raw rice in front of you and give a score for appearance, colour and aroma.

EVALUATION OF RAW RICE

PRODUCT: RAW RICE – SET 1 **NAME OF JUDGE:** ____________________

Reference scale	1 Dislike extremely	2 Dislike very much	3 Dislike moderately	4 Dislike Slightly	5 Neither like nor Dislike	6 Like slightly	7 Like moderately	8 Like very much	9 Like extremely

Code	APPEARANCE & COLOUR	Score	AROMA	Score	Overall degree of liking
Product 1 Rice 357					
Product 2 Rice 458					
Product 3 Rice 221					
Product 4 Rice 100					

EVALUATION OF COOKED RICE

PRODUCT: COOKED RICE – SET 1 **NAME OF JUDGE: ____________________**

Preference scale	1 Dislike extremely	2 Dislike very much	3 Dislike moderately	4 Dislike Slightly	5 Neither like nor Dislike	6 Like slightly	7 Like moderately	8 Like very much	9 Like extremely

Code	APPEARANCE & COLOUR	Score	AROMA & FLAVOUR	Score	TEXTURE & MOUTHFEEL	Score	Overall degree of liking
Product 1 Rice 889							
Product 2 Rice 705							
Product 3 Rice 007							
Product 4 Rice 630							

Focus group on raw and cooked rice 5 Sept/18 & 19 Sept/23 Sept/26 & 27 Sept

EXPECTATIONS **THIS FORM ONLY TO BE USED BY FACILITATOR**	
	EXPECTATIONS
1. What comes to mind first when you think of rice?	
2. When selecting raw rice what characteristics/attributes are important? WHY?	
3. When eating cooked rice what characteristics/attributes are important? WHY?	

GENERAL QUESTIONS **To be used by facilitator only**		
1. Rank the most important cooked rice characteristic: 1 preferred (if other attributes are more important indicate it here)		
White colour	Loose kernels	Firm
1. Describe good quality rice.		
2. Which brands do you buy the most? WHY?		
3. How important is brand?		
4. What price/kg are you willing to pay for rice that meets all your expectations?		

CHAPTER 6

PHYSICOCHEMICAL PROPERTIES OF LONG-GRAIN PARBOILED RICE RELATED TO EATING QUALITY

Abstract

Twelve long-grain parboiled rice samples, containing as much as possible variation, were sourced from all over the world and subjected to physicochemical evaluation. The tests conducted were all associated either directly or indirectly with the eating quality of parboiled rice. The tests included apparent amylose and protein content determination, the determination of the degree of gelatinisation and viscosity properties, texture measurement and the colour measurement of both the raw and cooked rice samples. The same twelve samples were also subjected to descriptive sensory analysis and the full sensory profile was established for each sample. The correlations between the sensory attributes and physicochemical measurements were investigated. Eight of the 12 samples were also selected to determine consumer preference and the drivers of consumer liking for long-grain parboiled rice, through consumer research. The correlations between consumer liking and the physicochemical measurements were investigated. The physicochemical measurements indicated that the physicochemical drivers responsible for sample clustering, were the degree of gelatinisation, colour and viscosity properties. Correlations observed between various physicochemical measurements included: a strong correlation between raw vs. raw, raw vs. cooked, and cooked vs. cooked colour measurements; both the Rapid Visco Analyser (RVA) and Differential scanning calorimeter (DSC) measurements showed significant ($p \leq 0.05$) correlations with the colour measurements; various RVA and DSC measurements were also strongly correlated.

1. Introduction

According to the literature, the eating quality of cooked rice *per se* is usually associated with the following sensory attributes: rice aroma and flavour; hardness; stickiness; whiteness; and glossiness (Juliano *et al*., 1965; Del Mundo, 1979). In Chapter 3 it was indicated that raw parboiled rice was characterised by “whiteness intensity”, “crushed maize kernel” aroma and “typical rice” aroma. Cooked parboiled rice was characterised by “whiteness intensity”, “swollen/plump” appearance, “firmness”, “typical rice” aroma, “typical rice” flavour, “springy/rubbery”, “maize porridge” aroma, and “grain-to-grain stickiness”.

Although these sensory attributes are all measurable and quantifiable, an array of chemical rice constituents could also be used to quantify eating quality. These constituents, coupled with different processing parameters during the parboiling process, impact directly on the product’s sensory quality and, hence, the eating quality as experienced by the consumer.

Starch, a major constituent of rice, accounts for more than 80% of the total components present in the rice kernel. Amylose, in turn, is the major compound influencing the physicochemical properties of rice starch (Zhou, 2002). Starch is, thus, regarded as the most important component of rice, in terms of functionality and cooking quality. The amount of amylose is usually measured spectrophotometrically, by measuring the extent to which iodine complexes with amylose. Although an official AACC method for measuring amylose content of milled rice is available, several factors can cause variations in the results (Bergman *et al*., 2004). Rice lipids compete with iodine when forming a complex with amylose. When a rice sample is defatted, the amount of amylose detected changes. The long chains of amylopectin also bind with iodine and, since rice samples vary in the amount of amylopectin chains, the amount of iodine bound will differ accordingly. These factors affect the resulting amylose value determined, to varying degrees. The amount of amylose can also be affected when calculating the amount of potato amylose and waxy rice starch used, to develop the amylose standard curve from which the amylose content is determined during anlaysis. The assumption is that rice contains 90% starch, but this is not always the case. In view of the above, researchers have suggested that amylose content (measured colorimetrically) should be reported as “apparent amylose” or “amylose equivalents” (Takeda *et al*., 1987; Radhika Reddy *et al*., 1993). In this study the amylose content will be reported as apparent amylose.

In addition to amylose content, pasting and gelatinisation properties are among the most crucial physicochemical properties of starch (Bao & Bergman, 2004). Rice starch granules undergo two sequential changes during the parboiling process; firstly, the starch is gelatinised, and secondly, the rice undergoes a process of re-crystallisation (Bhattacharya, 2004). Gelatinisation can be described as a two-step process. First the starch granule swells as a result of the breakage of the hydrogen bonds in the amorphous portions of the starch. Then, water acts as a plasticiser that leads to hydration, with subsequent swelling of the amorphous regions. A precursor of gelatinisation is the glass transition phase, where the amorphous regions of starch must first melt (Slade & Levine, 1988). During re-crystallisation of parboiled rice starch (in the final cooling and drying steps), the crystallinity increases, with the formation of crystalline amylose–lipid complexes (Derycke, 2007). These changes to crystallinity are accompanied by a gradual change from a viscous-amorphous state to a glassy state. The Differential Scanning Calorimeter (DSC) is the preferred instrument for the measurement of starch gelatinisation (Nakazawa *et al*., 1984; Shiotsubo & Takahashi, 1984; Wickramasinghe & Noda, 2008; Acquistucci *et al*., 2009; Wani *et al*., 2010). The DSC is a thermal analysis instrument that determines the temperature and heat flow associated with material transitions, as a function of time and temperature (Haines *et al*., 1998). Pasting properties have been used to predict the final product quality, in terms of cooked rice texture (Shu *et al*., 1998; Limpisut & Jindal, 2002). The Rapid Visco Analyser (RVA) is one of the instruments available for measuring the pasting properties (Bao, 2008) and the viscosity is measured in rapid visco units or in centipoise (cP).

Protein is the second most abundant constituent present in rice after starch, and protein (6.6-7.3%) is thus also considered an important factor, influencing product eating quality (Kim *et al*., 2004;

Singh *et al*., 1998; Xie *et al*., 2008). Martin and Fitzgerald (2002) removed protein from rice flour through a protease treatment and found that the absence of protein significantly influenced the RVA pasting curves. Their study showed that proteins influence viscosity curves through water binding and a network, linked together by disulphide bonds. Rice protein is typically measured by the Kjeldahl method, but other methods include quantification with Dumas and Near Infrared Spectroscopy (NIRS) (Delwiche *et al*., 1996; Bett-Garber *et al*., 2012).

Consumers consider the texture of cooked rice to be its main quality attribute (Okabe, 1979; Rousset *et al*., 1999). The texture of cooked rice is mainly influenced by the amylose and protein content present (Sandhya Rani & Bhattacharya, 1995; Champagne *et al.,* 1999; Meadows & Barton, 2002; Yifang & Harold, 2002; Yifang *et al.,* 2002). Stickiness is another eating quality attribute that consumers deem important. The amount of amylose present also determines the stickiness of rice. Freshly harvested rice tends to be stickier than aged rice (Mossman *et al*., 1983). Both texture (firmness) and stickiness can be measured by various instruments. The parboiling process, however, renders the rice kernels firmer and less sticky than raw rice grains (Raghavendra Rao & Juliano, 1970; Kimura *et al*., 1976; Pillaiyar & Mohandoss, 1981a).

Rice colour, both raw and cooked, is another important sensory characteristic for consumers. The raw rice colour is changed during the parboiling process and becomes darker and more yellow (Lv *et al.*, 2009). The degree of discolouration in the parboiling process is affected by the temperature and duration of the soaking and steaming steps, as well as the method of drying (Jayanarayanan, 1965; Johnson, 1965; Pillaiyar & Mohandoss, 1981b; Elbert *et al*., 2001). As indicated in Chapter 5, consumers have indicated that they prefer rice to be shiny and white in colour. The colour of raw and cooked parboiled rice can be determined by using a spectrophotometer and the CIE colour scales L*, a* and b*, while the whiteness (WI_{CIE}) and the yellowness (YI_{E313}) indices are calculated (CIE L*a*b* Colour scale, 2008).

The aim of this part of the study was threefold: firstly, to analyse the physicochemical attributes, directly and indirectly associated with the sensory quality of the rice; secondly, to determine the physicochemical drivers of sensory quality; and lastly, to determine the physicochemical drivers of consumer liking.

2. **Material and methods**

2.1 *Rice samples*

The same 12 long-grain parboiled rice samples, used during the profiling (refer to Chapters 3 and 4), were used in the physicochemical analysis. Refer to Table 1 for the list of samples, as well as their countries of origin.

2.2 *Rice preparation methods for descriptive sensory analysis (DSA) and consumer preference testing*

The samples were prepared as described in Chapter 3.

2.3 Physicochemical analyses

2.3.1 Colour measurements (raw and cooked rice)

Both the raw and cooked colour of the rice samples was determined, using the CM-5 spectrophotometer (Minolta, Tokyo, Japan). The standard observer was 10º and the illuminant was D65 (afternoon daylight). To ensure accurate readings on the instrument, both a zero and a white calibration were conducted, every time the machine was used. Once the calibration was completed and before sample analysis could commence, a green tile standard was measured on the instrument, to ensure that results were valid. Thereafter a sample cup was filled to 75% capacity with the respective rice samples, shaken lightly and tapped before being placed into the instrument. All samples were analysed in triplicate. The colour was recorded as a tristimulus of L*, a* and b* (Fig. 1). The L* value is the measure of brightness from black (0) to white (100), while a* describes the red-green colour, with positive a* values indicating redness and negative a* values indicating greenness. The b* value describes yellow-blue colour, with positive b* values indicating yellowness and negative b* values indicating blueness (Good, 2002). The whiteness Index (WI_{CIE}) was calculated, by using related CIE coefficients, while the yellowness index (YI_{E313}) was calculated, by using ASTM E313 method (ASTM, 2014).

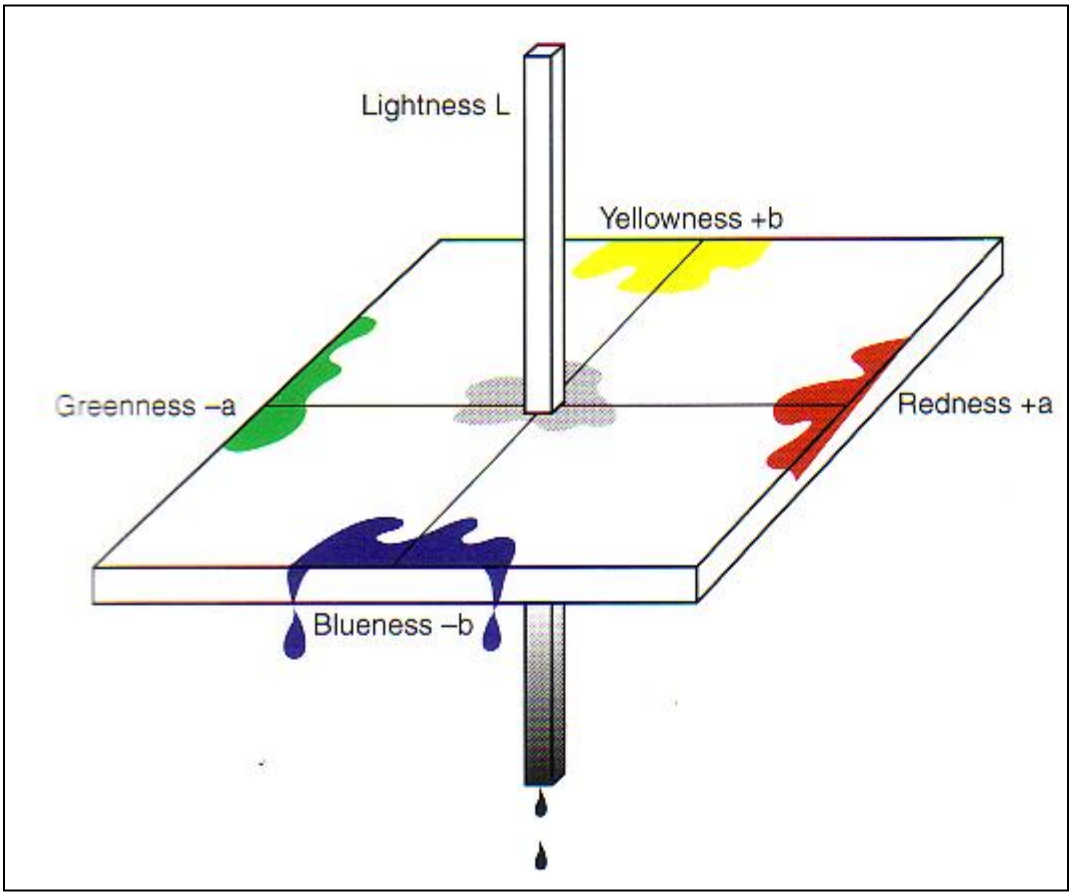


Fig. 1 L*, a*, b* colour space (Berns, 2000).

2.3.2 Moisture content determination

The moisture content of the rice samples was determined, using the AACC method 44-15A (AACC, 2014a). The rice samples were first milled on a laboratory mill (3100, Perten, Hägersten, Sweden), to pass through a 500-micron sieve. The various moisture dishes with lids were weighed to the nearest 0.001 g. Following that, 5 ± 0.001 g of each of the long-grain parboiled rice samples were placed in the respective moisture dishes and the weight recorded. The moisture dishes were then placed, uncovered, in an oven (Chopin EM10, Villeneuve-la-Garenne Cedex, France) for 1 h at 130°C. Afterwards the lids were placed back on the moisture dishes; the dishes were removed from the oven and subsequently placed in a desiccator for 45 min to cool. Following cooling, the mass of the covered dishes was recorded to the nearest 0.001 g and the moisture content determined. The moisture content of each rice sample was needed for the expression of protein results, as well as the calculation of the test weight for both the RVA and DSC analysis.

2.3.3 Texture analysis of cooked rice

Sample preparation. The rice samples were prepared, as outlined in the ISO method 11747 (ISO, 2012). Prior to the cooking of the rice samples, the moisture content of the samples was adjusted to be in the acceptability range of 13.0 ±1.0%. The required moisture addition was calculated by making use of the formula: Mass x (Target moisture %−Actual moisture %) / (100−Target moisture %). Following the water addition to the rice, the samples (sealed in honey jars) were transferred to a sealable bucket and rolled horizontally on an in-house rolling device for 1 h and left to stand overnight. After that, 20 g of rice sample was placed in a 100 mL beaker and 38 mL distilled water was added. Three replicate samples were prepared for each of the 12 rice variants. The three beakers were then placed onto a perforated metal plate, situated just above the cooking surface of a stainless steel saucepan, with the water already at boiling point (100°C). The saucepan was closed and the rice samples left to cook for 20 min. The saucepan was then removed from the stove and the samples were subjected to a resting period of 10 min. The beakers were then removed from the cooking vessel and placed upside down on watch glasses to cool at room temperature (20-25°C) for 1 h. After cooling, the cooked rice samples were removed from the beakers, divided into three sub-samples (17 g per sub-sample) and placed into plastic bags to prevent dehydration, until the measurement was conducted.

Texture analysis The resistance to extrusion of the cooked rice samples (measured in terms of firmness) was determined according to the ISO 11747 method (ISO, 2012), using the TA.XT plus texture analyser (Stable Micro Systems, Surrey, UK), with 250 kg load cell. The extrusion attachment consisted of compression probe (26 x 26 mm) and a compression cavity, with a perforated extrusion plate at the bottom of the cavity, which was mounted on a heavy-duty platform (Fig. 2). For each analysis, a rice sample of 17 g was placed in the test cavity. The test was executed at a speed of 1.6 mm/s until the sample was 100% compressed and extruded. The texture analyser automatically records the force applied during the compression process (firmness), as well as the force to lift the compression probe from the remaining sample in the test cavity (stickiness). Each rice sample was analysed nine times (3 glass beakers x 3 sub-samples per beaker). The firmness and stickiness data of the three sub-samples were averaged, to result in three triplicated measures for the respective rice samples. The firmness and stickiness results were reported in kg/7.5 cm^2 (testing area of the extrusion plate).

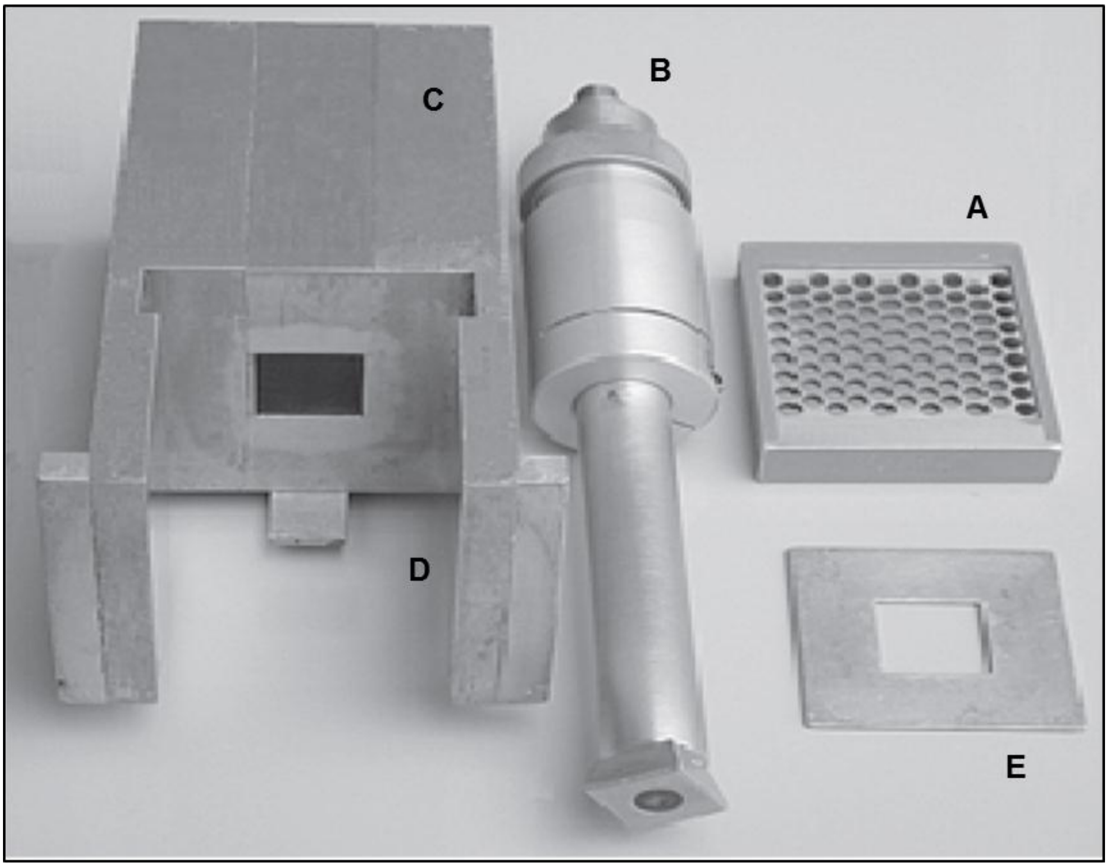


Fig. 2 Extrusion attachment fittings. Extrusion plate (A), compression probe (B), compression cavity (C), heavy duty platform (D) reductor for perforated plate (E) (ISO, 2012).

2.3.4 Differential scanning calorimeter (DSC)

The starch properties of the rice samples were determined, according to the method described by Derycke *et al*. (2005). The samples were first milled to pass through a 500-micron screen and then the moisture content was determined by the AACC method 44-15A (AACC, 2014a). Indium was used for calibration of the DSC instrument (HPDSC- 827, Mettler Toledo, Greifensee, Switzerland) and an empty aluminium pan was included as a standard reference. The DSC system worked with the STARe® thermal analysis software (Mettler-Toledo, Greifensee, Switzerland). Afterwards 10 mg of milled rice and 30 mg water (1:3 solid:water ratio w/w) were added in an aluminium pan, sealed and analysed with DSC from 40-100°C, at a rate of 10ºC/min. Any peak in a DSC thermogram is characterised by various temperatures (°C): the onset temperature (To); the peak temperature(s) (Tp); and the endset/offset temperature (Te) (Fig. 3). The area under the curve represents the enthalpy associated with the given thermal event and values are reported in J/g (Hydrateweb, 2014).

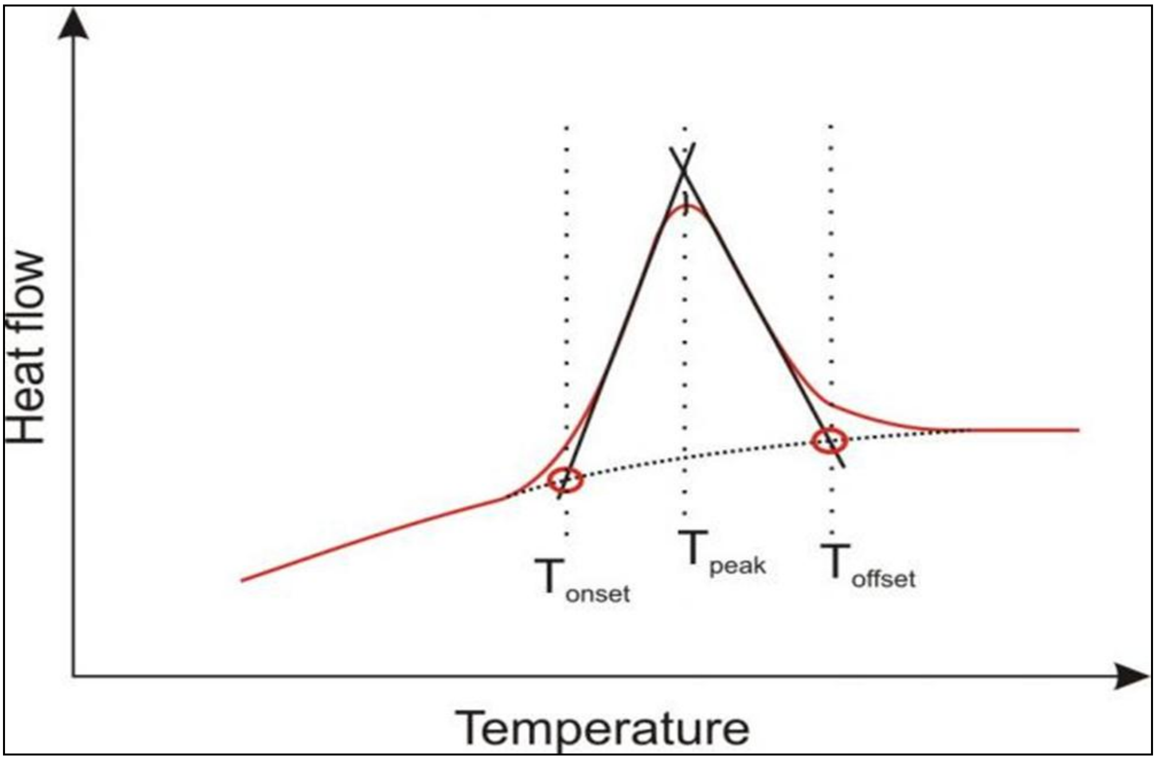


Fig. 3 Typical DSC thermogram (Hydrateweb, 2014).

2.3.5 Rapid Visco Analyser (RVA)

The pasting properties of the rice samples were determined, using the AACC method 61-02 (AACC, 2014b). To ensure that the RVA instrument (Perten, Hägersten, Sweden) was performing within specification, a test profile had to be loaded onto the instrument. Prior to the analysis, the rice samples were milled on a laboratory mill (3100, Perten, Hägersten, Sweden) to be able to pass through a 500-micron sieve and adjusted to a 12% moisture basis (refer to moisture analysis in 2.3.2). Thereafter, 3 g rice flour was slurried with 25 ±0.1 mL water in an aluminium canister. The test profile has a starting temperature of 50°C, which was held for 1 min, raised to 95°C in 4.8 min, held for 7.3 min, cooled to 50°C in 11.1 min, and held for 12.5 min. Stirring speed was 960 rpm for 10 s and 160 rpm for the remainder of the test period. The RVA instrument provided the following parameters: peak viscosity (PV), which indicates the highest viscosity during ‘‘heating’’; time to peak viscosity; holding strength or trough, which indicates the lowest viscosity following PV; breakdown (BD), which is determined by PV minus T; final viscosity (FV), which indicates the viscosity at the completion of the cycle and setback (SB), which is calculated by FV minus PV (Fig. 4). Values are reported in min, °C or Rapid Visco Analyser units (RVU), each of which is approximately equal to 10 mPas (Ross *et al*., 1987).

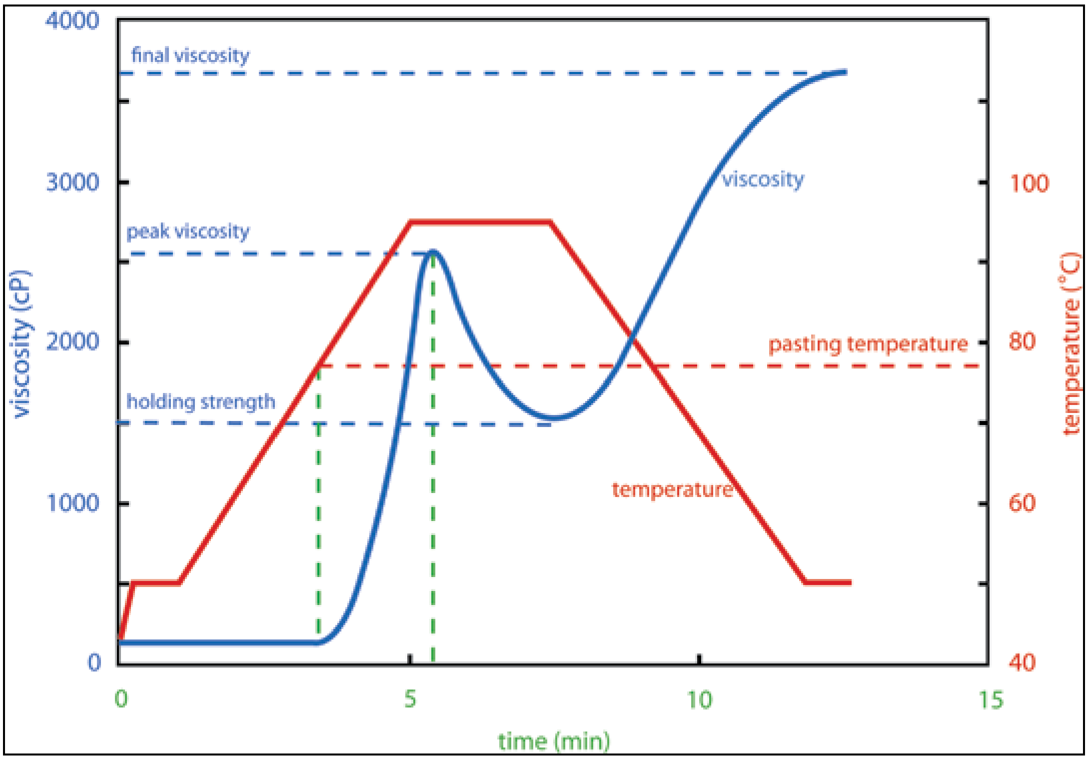


Fig. 4 Typical RVA pasting curve (Perten, 2014).

2.3.6 Amylose content determination

The amylose content of the rice samples was determined, using the AACC method 61-03 (AACC, 2014c) and a spectrophotometer (Beckman Coulter, USA). To ensure amylose content could be determined, a standard curve was compiled, by plotting the absorbance of solutions containing various ratios of potato amylose and waxy rice flour, which represent all levels of amylose anticipated in the test samples, at 620 nm. Once the standard curve was plotted, the test samples were analysed. At least 20 grains of each rice sample was milled on a laboratory mill (3100, Perten, Hägersten, Sweden) to pass through a 500-micron sieve. The samples were left uncovered for 2 d, for the moisture content to equilibrate to the laboratory environment. Each rice sample was assessed in triplicate, by transferring 20 mg of rice flour from each sample into a test tube. Then, 0.2 mL of 95% ethanol was added and the test tubes mixed with a vortex mixer. Afterwards, 1.8 mL 1 N NaOH was added to each sample; the samples remained at room temperature for 2 min. The samples were then heated in a scientific water bath for 2 min, removed and allowed to cool down to room temperature for at least 2 h. Thereafter, 18 mL distilled water was added to each of the samples and mixed. Following this, 1 mL aliquots of each rice sample solution was pipetted into 25 mL test tubes, already containing 5 mL distilled water. Then, 0.2 mL 1 N acetic acid was added and the solution mixed; 0.4 mL iodine solution was then added, as well as 14.4 mL distilled water, and the solution thoroughly mixed. The solutions then stood for 20 min before the analysis commenced. For the reference sample, 1 mL 0.09 N NaOH was used, which was used to calibrate the spectrophotometer. The colour absorbance at 620 nm was then measured and recorded for all samples in triplicate.

2.3.7 Protein content determination

Protein content of the rice samples were determined according to the AACC method 46-30 (AACC, 2014d), using a DUMAS combustion analyser (Trumac® N, supplied by Leco Africa). To ensure that the instrument was performing within specifications, a number of blank samples, followed by a number of ethylenediaminetetraacetic acid (EDTA) samples were analysed, prior to the protein determination. Ethylenediaminetetraacetic acid (nitrogen content: 9.57%) was used to calibrate the instrument. The EDTA standard (0.1 ± 0.001 g) was weighed off into a ceramic boat and placed on the carousel loading head of the instrument. The rice samples were first milled on a laboratory mill to pass through a 500-micron sieve. Once the instrument was calibrated, the rice samples (0.5 ± 0.001 g) were weighed off into the ceramic boats and loaded into the instrument and the nitrogen content was measured. In order to convert the nitrogen to protein, a conversion factor of 6.95 was used. Afterwards the protein content was expressed on a 12% moisture basis (mb). All samples were analysed in triplicate.

2.4 Statistical procedures

Analysis of variance tested whether the samples differed significantly ($P \leq 0.05$) in terms of the physicochemical measurements conducted. Principal component analysis was used to visualise and explain the relationship between the physicochemical measurements and individual samples. Partial least squares regression was then conducted to relate the physicochemical measurements to the descriptive sensory analysis, as well as the consumer liking of the rice samples. Pearson’s correlation coefficients were calculated for the physicochemical measurements, with both descriptive sensory analysis attributes and consumer liking. All data were analysed, using Statistica 12 software (Statsoft, Inc., Tulsa, Oklahoma, USA).

3. Results and discussion

3.1 Multivariate relationships between physicochemical measurements

For the sake of brevity, only the most important and applicable results will be reported and discussed here.

The ANOVA results determined significant ($p \leq 0.05$) differences between the sample means for all of the colour readings. The mean colour scores for the 12 samples are listed in Table 2 for the raw and Table 3 for the cooked rice samples.

When considering the mean L* values for the *raw rice,* it was evident that all samples tended more toward the whiteness side of the colour space, indicating that the samples were lighter in colour. Indian, Vietn, HDawn, Tasia and Arroz were significantly ($p \leq 0.05$) lighter than the rest of the samples, with WW and RiceL being most dark. The mean a* values for all the samples, although very low, were positive, indicating that the samples tend to be slightly more toward the red side of the colour space. Spekko and RiceL were significantly ($p \leq 0.05$) more red than the other samples, with AM, PY, Indian, Tasia and Vietnam the least red. The positive mean b* value results indicated that all samples tend more toward the yellow side of the colour space. Vietn was the least yellow in colour and Spekko, AC and Tastic was significantly more yellow than the rest of the samples. Whiteness Index (WI) and yellowness Index (YI) were mathematically calculated, using the measured CIE coefficients and ASTM E313 method, respectively; these indices give an indication of the whiteness and yellowness of the given rice sample, respectively (Kratochvil & Novak, 1994). Indian, Vietn and Tasia had the highest WI and were significantly ($p \leq 0.05$) less yellow than the rest of the samples in terms of YI. Similarly Tasia, Spekko and AC have the highest YI and were significantly lower on the WI, than the rest of the samples.

The high positive mean L* values of the *cooked rice* samples indicated that they tended more towards the whiteness side of the colour space, but significant ($p \leq 0.05$) differences between the samples were evident. Indian, Tastic and Vietn were significantly ($p \leq 0.05$) lighter than the rest of the samples, and HDawn, WW and Tasia were the darkest of all the samples. When considering the mean a* values only two samples, namely Spekko and AC, were positive, indicating that they tend more toward the red side of the colour space, whilst the rest of the samples were more toward the green side of the colour space. Indian and Vietn were significantly ($p \leq 0.05$) more green than the rest of the samples. The mean b* values for the cooked samples were all positive, indicating that all samples tend toward the yellow side of the colour space. Samples AC, Spekko, Tastic and RiceL were significantly ($p \leq 0.05$) more yellow and subsequently also had lower means in terms of WI. Indian, Vietn and PY had significantly ($p \leq 0.05$) higher means in terms of WI and subsequently lower means on YI.

When comparing the raw and cooked sample results, the Indian sample was the only sample that had both the lightest L* value when raw and when cooked. Similarly, according to the a* values, Spekko was the most yellow in the raw and cooked state. Vietn was the least yellow out of all the samples, in both its raw and cooked state.

The colour measurements observed here indicated that the mean L* value for cooked rice was higher than the L* value for raw rice, indicating an increased whiteness in the cooked state; similarly the a* and b* mean values were higher in raw rice than they were in cooked rice. When comparing the values for the mean L* value raw to that of its cooked counterpart, there was no obvious relationship; high a* and b* values in raw rice samples were also high on the corresponding cooked samples. When the L*, a* and b* cooked rice mean values were compared, there did not seem to be a relationship evident; however, when comparing the L*, a* and b* raw rice mean values, it was evident that once the L* value increased, both the a* and the b* value decreased.

There may be many processing factors contributing to the colour differences detected between the samples. Since parboiled rice is produced by the process of parboiling, followed by a subsequent milling process, both these steps can influence the colour of the rice. During the parboiling process, the soaking time and temperature, steaming time and temperature, as well as the method used during drying, can all influence the extent to which the rice will change in colour (Jayanarayanan, 1965; Johnson, 1965; Pillaiyar & Mohandoss, 1981a; Elbert *et al*., 2001;). Research done by Lamberts *et al*. (2007) indicated that the L* value of raw rice kernels increased, while the a* and b* values decreased, until the degree of milling (removal of bran and outer endosperm) was 15%; further milling did not affect the L* value. Similarly, the L* value of cooked rice increased and the a* value decreased until the degree of milling reached 9%; further milling did not affect the L* value. The b* value of cooked rice decreased as the degree of milling increased and continued to decrease with degree of milling above 9%. The decrease in both the b* value (yellowness) and a* value (redness), with the increase in the degree of milling, was explained by the loss of pigments, as well as the water uptake during cooking, which diluted the leftover pigment present in the rice kernels (Bett-Garber *et al.,* 2012). Next to parboiling and milling, the storage temperature of rice plays a major role in potential colour changes. Jang *et al*. (2009) found that the b* value (yellowness) increased with the increase of storage temperature. Storage time is another factor that has a part to play in rice discolouration. Research conducted by Lee *et al*. (2001) showed an increase in the b* value of cooked rice, with the increase of storage time from one to three years, when the rice was stored at 4°C. The possible reason for this observation was the Maillard reaction taking place during storage. Moisture content did not have a substantial effect on yellowing of rice (Dillahunty *et al*., 2001).

When the correlation coefficients for colour measurements were investigated (Table 9-11), it was seen that L* raw, WI cooked and WI raw were positively correlated. These measures were, however, negatively correlated to a*, b* and YI raw, as well as a*, b* and YI cooked, which in turn were all positively correlated with each other.

The mean results for the 12 rice samples in terms of firmness, shown in Table 4, indicate that AC was significantly ($p \leq 0.05$) firmer than the rest of the samples, whilst WW and lastly HDawn was the softest. Spekko, AM and Arroz were significantly ($p \leq 0.05$) less sticky, whilst Tasia and RiceL were significantly ($p \leq 0.05$) stickier than the rest of the samples. Cultivar, storage temperature and storage duration influenced the texture of cooked milled rice (Lima & Singh, 1993). Additionally, the amylose and protein content, age, as well as the severity of the parboiling process of the rice, all influence parboiled rice texture as well. During the heating step in parboiling, complexes between rice lipids, with amylose, can occur (Priestley, 1976). The starch gelatinisation temperature, as well as the hydrothermal conditions to which the rice is subjected during the parboiling process, greatly determined the level and type of amylose-lipid complexes formed (Biliaderis *et al*., 1993). If similar heat/moisture conditions occur during cooling of parboiled rice, formation of amylose-lipid complexes may be reinforced during cooling. The firmer texture of parboiled rice may be linked to the level of crystalline amylose-lipid complexes formed during parboiling, because these complexes are stable in the cooking process (Priestley, 1976; Biliaderis *et al*., 1993; Ong & Blanshard, 1995).

When considering the correlation coefficients (Table 9 and 10), it can be seen that neither firmness nor stickiness correlated well with any other physicochemical measurement. Juliano and Pacaul (1980) and Windham *et al.* (1997) determined in their studies that rice firmness was positively correlated to amylose content, whilst stickiness was negatively correlated to the amylose content. In their study, Yu *et al.* (2009) found that rice firmness showed a positive correlation with the DSC measurement of enthalpy. The lack of correlation was unexpected, since correlation with RVA measurements, amylose and protein, as well as DSC measurements, was expected. A possible reason for this might be that only a few samples were used in this study, and the limited amount of variability between the samples.

Parboiling has a noticeable effect on the pasting behaviour of rice (Ali & Bhattacharya 1980). Pasting temperature is raised, while peak viscosity, breakdown and setback are all lowered by parboiling (Raghavendra Rao & Juliano 1970). Mean RVA results for the 12 rice samples, for peak viscosity, indicated that there were significant ($p \leq 0.05$) differences between the rice samples (Table 5). Peak viscosity is regarded as the highest viscosity reached during the heating phase of the RVA method. At this point the majority of granules are fully swollen, but intact. Native starch has a higher peak viscosity than heat-treated starch. During the parboiling process, a variable amount of starch is pre-gelatinised, the extent of this being determined by the severity of parboiling. The higher the parboiling severity, the less the number of native granules available for hydration, and the lower the peak viscosity (Himmelsbach *et al*., 2008). Vietn had a significantly ($p \leq 0.05$) higher peak viscosity, while Spekko, AC and Tastic had the lowest peak viscosity. Possible reasons for the observed differences in pasting characteristics between the parboiled rice samples include that the starch granules were disrupted by gelatinisation and were therefore not in a position to swell as much as native starch. Furthermore, the partial starch retrogradation, following gelatinisation (Ali & Bhattacharya, 1976), binds the granular structure together and inhibits swelling. Another reason for the differences between samples can be attributed to the rice starch forming amylose-lipid complexes during the parboiling process. These amylose-lipid complexes are inhibitors of the swelling of rice (Tester & Morrison, 1990). The severity of the parboiling process influences to what extent amylose-lipid complexes are formed in the rice. These results indicated that Spekko, AC and Tastic were produced through a more severe parboiling process.

The mean results for final viscosity also indicated that there were significant ($p \leq 0.05$) differences between the rice samples. HDawn had a significantly ($p \leq 0.05$) higher final viscosity, followed by Vietn, whilst Spekko, AC and Tastic had a significantly ($p \leq 0.05$) lower final viscosity than the rest of the samples. Final viscosity is an indicator for the starch's ability to form a viscous paste after cooking and cooling. This is related to final product texture after cooking. Samples with low final viscosities are firmer, while samples with high final viscosities are softer. The setback viscosity is also indicative of final product texture and there were similarities between the final viscosity and the setback viscosities of the different samples, with the exception of Indian and Vietn, as well as PY and RiceL. Refer to Fig. 5 for the RVA pasting curves for the 12 rice samples.

The mean DSC results for the 12 rice samples indicated that there were significant ($p \leq 0.05$) differences between the various samples, in terms of their degree of gelatinisation (Table 6). The gelatinisation temperature is a narrow temperature range at which starch granules begin to swell, lose crystallinity and the viscosity increases (Himmelsbach *et al.*, 2008). The exact temperature at which starch begins to undergo these changes, is referred to as the gelatinisation onset temperature. The degree of starch gelatinisation was determined by comparing the mean gelatinisation enthalpies (ΔH) (the measure of the total energy of a thermodynamic system) of the various rice samples to that of the control, a non-parboiled Basmati rice sample (Fig. 6). The large ΔH for raw rice indicates the absence of gelatinised starch, and similarly, the more gelatinised the rice becomes by being exposed to a higher severity of the parboiling process, the smaller ΔH becomes. Marshall *et al.* (1993) used the following formula to calculate the degree of gelatinisation: gelatinisation % = $(1 - \Delta H_{par}/\Delta H_{raw}) \times 100$; where ΔH_{par} is the enthalpy of gelatinisation of the parboiled sample and ΔH_{raw} is the enthalpy of the raw or native sample. This formula assumes that the raw sample contains no gelatinised starch. When comparing the mean results for ΔH, it was evident that Vietn had the least amount of gelatinised starch, whilst AC, Tastic and RiceL had the most gelatinised starch present. Six types of endotherms, associated with starch, are said to exist (Table 7). The reported endotherms include starch gelatinisation, annealed starch, retrograded amylopectin, lipid-amylose complex I, lipid-amylose complex II and retrograded amylose (Biliaderis *et al*., 1986; Mestres *et al*., 1988; Biliaderis & Galloway, 1989; Biliaderis, 1992).

Significant ($p \leq 0.05$) differences in peak temperatures between samples were also noted in the ANOVA results (Table 6). When considering the peak temperature of the control sample (non-parboiled), it was evident that the peak was at a much lower temperature than any of the parboiled rice samples. Biliaderis and Galloway (1989) found that two types of lipid-amylose complexes were formed during parboiling and were dependent on the crystallisation temperature. Lipid-amylose complex I (L-Am I) was formed at lower temperatures and was not crystalline, but amorphous and had no birefringence. Lipid-amylose Complex II (L-Am II), on the other hand, was more crystalline. These two lipid-amylose complexes are responsible for causing the resistance to cooking in parboiled rice. L-Am I, which melted ± 100°C, had no serious implications on cooking time, since it melted at boiling temperature while the rice was cooked, L-Am II, however, did not melt at boiling point and was the main culprit leading to the increased cooking time of parboiled rice. When considering the melting region of L-Am I (Table 7), it is evident from the results that only three samples – AM, PY and Arroz – contained L-Am I. Unfortunately, since the samples were only heated to 100°C, it is unclear if any of the samples contained L-Am II. The presence or absence of retrograded starch can also be determined with DSC analysis. When considering the samples in this study, it was evident that no retrograded amylopectin was present in any of the samples and no retrograded amylose, as the samples were only heated to 100°C (a mild acid hydrolysis is required to destroy the acid labile retrograded amylopectin to increase the relative abundance of amylose, within a sample).

When considering the correlations of the DSC measurements, positive correlations were evident between enthalpy and both WI raw and cooked. This correlation was expected, since the WI will increase if more ungelatinised starch is present. Another expected correlation was that of enthalpy with the RVA measurements. The more ungelatinised starch the rice contained, the higher the viscosity measurements.

Mean results for the 12 samples measured for apparent amylose content indicated that significant ($p \leq 0.05$) differences were noted between the samples. Samples PY, Spekko and Tastic had the highest amount of amylose, whilst RiceL and WW the lowest amount (Table 8). The rice samples can be classified, according to amylose content, in the following classes: waxy (0-2% amylose dry basis); low (10-20%); intermediate (20-25%) and high (>25%) (Juliano, 1972). All the rice samples, with the exception of Indian, RiceL and WW, could be classified as high amylose rice. Indian, RiceL and WW can be classified as intermediate amylose rice. Researchers found that the total amylose content remains essentially unchanged by the parboiling process (Raghavendra Rao & Juliano, 1970; Ali & Bhattacharya, 1972). As mentioned in Chapter 2, the USA classifies rice as long, medium or short grain. This classification does not only denote kernel length, but also includes a combination of many characteristics, of which amylose content is only one. According to this classification, USA long-grain rice has an amylose content ranging from 19-23%, medium-grain rice an amylose content of 12-19%, and short-grain rice, an amylose content of 12-19% (Anon., 2014). According to this classification, both RiceL and WW, which originate from the USA, can be classified as being long grain, according to the USA classification, but as intermediate on the classification that is used by the rest of the world. Numerous sensory characteristics can be associated with this amylose content classification. Low amylose content rice tends to be sticky and soft when cooked, while high amylose rice tends to be more loose and firm upon cooking (Sandhya Rani & Bhattacharya, 1985, 1989).

When investigating the correlation coefficients in Tables 9-11, it was evident that there were no significant correlations between amylose and the remaining physicochemical data. This might be due to the fact that most of the rice used in this study were long grain and had amylose contents > 25% within a limited range, with the exception of the two American rice samples.

The mean results for protein content showed that Tastic had significantly ($p \leq 0.05$) higher protein content, whilst Arroz and Tasia had the least amount of protein (Table 8). High-protein rice is less sticky and has a harder texture; it was found that rice protein consists mainly of glutelin and oryzenin, which form a complex with starch that decreases rice stickiness (Chrastil, 1990). Amylose content has been considered one of the most important characteristics for the cooking behaviour of rice (Xie *et al*., 2008). Champagne *et al*. (1999), however, demonstrated that many cultivars with similar amylose contents showed slightly different pasting and textural properties. Singh *et al*. (2000) found that the differences in amylograph viscosity, between flour and starch of rice, suggested that components other than amylose also affected the cooking properties of rice. During the heating step of the parboiling process, disulphide bonds between components of the rice protein fraction are formed. Since the effects of reduction of disulphide bonds, during cooking, were shown to be opposite to the changes in cooking properties induced by parboiling, it has been suggested that formation of disulphide bonds during parboiling is also responsible for changes in cooking properties (Derycke *et al*., 2005). The heat/moisture conditions during parboiling, as well as the cooling and drying process, and the important structural changes in the rice kernels associated with the process, have a significant impact on the properties of cooked parboiled rice (Pillayar & Mohandoss, 1981a, b). After the completion of parboiling, the protein bodies in the rice are ruptured and the solubility is reduced (Raghavendra Rao & Juliano, 1970). The protein content of milled rice, as well as the amino acid composition of the protein, seems to be unaffected by parboiling (Bhattachraya & Ali, 1985).

The correlation results in Table 9-11 indicated negative correlation between the protein content and the measurements of the RVA and DSC, respectively. No other significant correlations were evident between protein and the remaining physicochemical measurements. A study conducted by Suwannaporn *et al.* (2007) established that there was no correlation between amylose content and protein content.

The above findings are summarised in the PCA bi-plot (Fig. 7), which displays the association between the physicochemical measurements of the 12 long-grain parboiled rice samples. The first principal component (PC1) explained 52% of the variation in the data and the second principal component (PC2) 17%. From the PCA bi-plot it is evident that certain samples grouped together, and three distinct clusters can be seen, indicated as Group 1, 2 and 3. The main physicochemical measurements, associated with the samples in Group 1 (PY, Arroz and AM), were the DSC measurements; i.e. onset, peak and endset. In Group 2 (Vietn, Indian, Tasia and HDawn) the main measurements associated with these samples were the colour measurements, i.e. L* raw, WI raw and cooked, as well as the DSC measurement, enthalpy and the RVA measurement, peak viscosity. The main measurements driving the association in Group 3 (Tastic, WW, RiceL, AC and Spekko) were the colour measurements a*, b* and YI raw, as well as a*, b* and YI cooked. In Chapter 5 consumers indicated a preference for samples Vietn, Tasia and AM. Vietn and Tasia formed part of Group 2, whilst AM formed part of Group 1.

3.2 Multivariate relationships between the sensory profile (DSA) and physicochemical measurements

In Chapter 3 the sensory attributes of 12 long-grain parboiled rice samples were determined. In Chapter 5 eight samples, which were dissimilar in their overall sensory profile, were selected to gain insight into the drivers of consumer preference for long-grain parboiled rice. The multivariate relationship between the sensory profile and the consumer preference was established (Chapter 5) and the sensory attributes associated with consumer liking determined. It was found that “whiteness intensity” was the sensory driver for raw long-grain parboiled rice liking. The sensory drivers for the cooked long-grain parboiled rice liking were determined to be: “stickiness in mouth”; “grain-to-grain stickiness”; “swollen/plump”; “starchy after 5 chews” and “whiteness intensity”, all associated with the primary attributes of texture and appearance. The cooked rice properties were further found to be more the drivers of liking than the raw rice properties. The objective was to determine if there were any relationships evident between the sensory drivers of liking and the physicochemical measurements.

In the PLS plot, indicating the correlation between physicochemical measurements and raw sensory attributes (Fig. 8a), the variation was mostly explained by Dimension 1 and less so by Dimension 2, and in total 69% of the variation was explained by the first two dimensions. Similarly in the PLS plot, indicating the correlation between physicochemical measurements and cooked sensory attributes (Fig. 9a), the first two dimensions explained 68% of the variation. It was evident from Dimension 1 that the texture attributes were driving the association, while on Dimension 2 aroma attributes were driving the association. When considering the raw (Fig. 8a) and cooked (Fig. 9a) PLS plots, it can be seen that there was a good correlation between certain sensory profile attributes (DSA) and certain physicochemical measurements. These correlations are better understood by investigating their significant correlation coefficients (Table 12-15). Only the correlation coefficients of the DSA attributes associated the drivers of liking, as determined in Chapter 5, will be discussed here. These mainly exclude aroma and flavour attributes of both raw and cooked rice. The results indicated an anticipated strong positive correlation of both the sensory attributes "whiteness intensity R" and "whiteness intensity C" with the colour measurements: L* raw, WI raw and cooked. Consequently these two sensory attributes are negatively correlated to a* value both raw and cooked; b* value both raw and cooked; as well as the YI value both raw and cooked. The attribute "grain-to-grain stickiness C" showed strong positive correlations with the DSC measurement of enthalpy and all of the RVA measurements (peak, final viscosity and set viscosity). Similarly the attribute "swollen/plump" showed a strong positive correlation with the RVA measurements as well as with the DSC measurement of enthalpy. These correlations for these two attributes were expected, since the higher the enthalpy, the more ungelatinised the samples and ungelatinised samples are characterised by an increased stickiness due to the availability of native starch granules; more gelatinised starch granules showed a resistance to swelling.

When comparing the corresponding score plots of the raw (Fig. 8b) and cooked (Fig. 9b) rice samples, it can be seen that there were similar sample groupings. The raw sample configurations are based on their difference in colour, with the physicochemical measurements associated with whiteness and lightness being in the direction of the sensory attribute "whiteness intensity". The association of the various cooked samples show that Vietn, Indian, Tasia and HDawn group together mainly on the basis of the following physicochemical measurements: L* raw, WI raw, WI cooked, enthalpy (DSC) and RVA measurements. PY, Arroz and AM group together mainly on the basis of the physicochemical measurements: amylose, firmness, stickiness, and the DSC measurements: onset, peak and endset. The samples Tastic, Spekko, AC, RiceL and WW group together mainly on the basis of the colour measurements: a*raw, b* raw, YI raw, a* cooked, b* cooked and YI cooked.

The sensory profile score plot as depicted in Chapter 3 in comparison to the sensory score plots of the raw (Fig. 8b) and cooked (Fig. 9b) rice samples compare well, indicating that the sensory profile and the physicochemical measurements classify the rice samples in a similar way.

3.3 Multivariate relationships between consumer preference and physicochemical measurements

The PLS plot (Fig. 10a) indicates the association of the physicochemical measurements with consumer preference. It is evident from the plot that there was weak correlation between the consumer liking data and the physicochemical measurements. It is evident, however, that some of the physicochemical measurements were in the direction of the consumer preference. This observation is further investigated by scrutinising the various correlation coefficients in Table 16 and 17. Raw overall liking and L* raw showed a strong positive correlation. Similarly for the cooked appearance liking, strong positive correlations between L* raw, WI raw and WI cooked were evident. It was interesting to note that no applicable correlations were evident with cooked texture liking. In terms of cooked overall liking, strong positive correlations were evident with L* raw WI raw and WI cooked. It can further be seen that the score plot (Fig. 10b) has a similar sample configuration to that of the PCA bi-plot (Chapter 5), indicating the association of the samples with the degree of liking attributes.

4. Conclusions

The physicochemical measurements that respectively drive the sample configuration can be seen as the degree of gelatinisation (samples PY, Arroz and AM showing evidence of L-AM-I complexes), colour, specifically whiteness or yellowness inherent to the samples, and lastly the viscosity properties. Physicochemical drivers can be concluded to be colour, degree of gelatinisation and viscosity properties.

The measurements of firmness, stickiness and protein showed no significant correlation to any physicochemical measurements, whilst the remaining physicochemical measurements had significant correlations with one another. There was a strong correlation between raw vs. raw, raw vs. cooked and cooked vs. cooked colour measurements. Both RVA and DSC measurements also showed significant correlations with the colour measurement. As soon as the parboiling process becomes more severe, it has an impact on all three these factors, namely colour, degree of gelatinisation and viscosity, and is most probably is the reason for the strong correlations. The RVA and the DSC measurements were also strongly correlated.

It was established in Chapter 5 that appearance and colour attributes were the main drivers of consumer liking with specifically “whiteness intensity”, which significantly influenced consumer liking of raw rice. The preference for cooked rice was driven by appearance, colour and texture. The “whiteness intensity”, “grain-to-grain stickiness” and “swollen/plump” significantly influenced consumer liking for appearance, while “stickiness in mouth”, “swollen/plump”, “starchy after 5 chews” and “grain-to-grain stickiness” significantly influenced consumer liking for texture. The correlation results between the physicochemical measurements and “whiteness intensity” (DSA attribute for consumer liking) indicated strong correlation with L* raw, WI raw and WI cooked, which was anticipated. The correlation results for “grain-to grain” stickiness and “swollen/plump” showed a strong correlation with the RVA measurements as well as the DSC measurement of enthalpy, direct measures of final product viscosity and the degree of gelatinisation. The attribute “starchy after 5 chews” was strongly correlated with the WI raw. The attribute “stickiness in mouth” did not correlate well with PC1 or PC2 and hence no correlation with this attribute and the physicochemical measurements could be established.

The correlations for the raw liking and the physicochemical data indicated that the raw and cooked colour measurements were strongly correlated, as well as firmness and amylose content. Similarly for the cooked liking and the physicochemical data, there was a strong correlation between both the raw and cooked colour measurements.

The coincidence of numerous structural changes that occur in the rice kernel during parboiling makes it hard to relate specific changes to specific sensory properties of parboiled rice.

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Table 1 Twelve long-grain parboiled rice samples used in the study.

Country of origin	Conventional name	Abbreviation/name used in this study
North America	Riceland	RiceL
	Woolworths	WW
India	Indian	Indian*
	Harvest Dawn	HDawn
Vietnam	Vietnam	Vietn
Thailand	Tasia	Tasia
	Spekko	Spekko
	Tastic	Tastic
	Aunt Caroline	AC*
South America	Americano	AM
	PY	PY*
	Arroz	Arroz*

*Samples omitted in the consumer research part of the study.

Table 2 Mean colour measurements relating to raw rice colour of the 12 rice samples.

Samples	[1]Mean L*value	[1]Mean a*value	[1]Mean b*value	[1]Mean WI_{CIE}	[1]Mean YI_{E313}
AC	65.21 ^{c}	3.11 ^{b}	27.32 ^{b}	-130.54^{f}	47.87^{b}
Indian	67.29 ^{a}	1.49 ^{g}	22.49 ^{g}	-97.12^{a}	39.83^{g}
Vietn	67.31 ^{a}	0.77 ^{i}	22.07 ^{h}	-94.96^{a}	39.12^{h}
HDawn	67.03 ^{a}	2.56 ^{d}	23.26 ^{f}	-101.81^{b}	41.20^{f}
PY	66.39 ^{b}	1.85 ^{f}	23.30 ^{f}	-104.24^{b}	41.36^{f}
AM	65.49 ^{c}	2.21 ^{e}	25.72 ^{d}	-120.89^{d}	45.36^{d}
Spekko	64.52 ^{d}	3.70 ^{a}	28.04 ^{a}	-136.48^{g}	49.25^{a}
Tastic	65.47 ^{c}	2.80 ^{c}	26.55 ^{c}	-125.42^{e}	46.66^{c}
Tasia	67.22 ^{a}	1.29 ^{h}	22.27 ^{gh}	-96.10^{a}	39.49^{gh}
RiceL	62.33 ^{f}	3.64 ^{a}	26.95 ^{e}	-137.21^{g}	48.79^{a}
Arroz	67.43 ^{a}	2.32 ^{e}	24.63 ^{e}	-108.64^{c}	43.02^{e}
WW	63.29 ^{e}	3.03 ^{b}	26.06 ^{d}	-129.25^{f}	47.00^{c}

[1]Values with the same superscript are not significantly different (P>0.05).

Table 3 Mean colour measurements relating to cooked rice colour of the 12 rice samples.

Samples	[1]Mean L*value	[1]Mean a*value	[1]Mean b*value	[1]Mean WI_{CIE}	[1]Mean YI_{E313}
AC	74.88 ^{ed}	0.21 ^{a}	16.17 ^{a}	-41.25^{g}	27.90^{a}
Indian	77.05 ^{a}	-0.98 ^{e}	10.49 ^{g}	-5.32^{a}	1.18^{g}
Vietn	76.55 ^{ab}	-1.26 ^{f}	9.98 ^{h}	-3.74^{a}	17.38^{g}
HDawn	74.56 ^{e}	-0.22 ^{b}	12.40 ^{d}	-21.37^{cd}	21.92^{d}
PY	75.65 ^{c}	-0.87 ^{de}	11.34 ^{f}	-13.11^{b}	19.84^{f}
AM	75.65 ^{c}	-0.90 ^{de}	12.81 ^{d}	-21.25^{cd}	22.26^{d}
Spekko	75.98 ^{cb}	0.21 ^{a}	15.20 ^{b}	-33.18^{f}	26.12^{b}
Tastic	76.92 ^{a}	-0.24 ^{b}	13.91 ^{c}	-23.98^{d}	23.84^{c}
Tasia	74.28 ^{e}	-0.78 ^{d}	11.87 ^{e}	-19.24^{c}	21.03^{e}
RiceL	75.71 ^{c}	-0.33 ^{bc}	14.05 ^{c}	-27.73^{e}	24.30^{c}
Arroz	75.55 ^{cd}	-0.84 ^{d}	12.39 ^{d}	-19.15^{c}	21.63^{de}
WW	74.44 ^{e}	-0.37 ^{c}	13.67 ^{c}	-28.77^{e}	24.00^{c}

[1]Values with the same superscript are not significantly different (P>0.05).

Table 4 Mean firmness and stickiness values relating to cooked rice texture for 12 rice samples.

Samples	[1]Mean firmness (kg/7.5cm²)	[1]Mean stickiness (kg/7.5cm²)
AC	12247.66 ^{a}	-1393.46 ^{de}
Indian	9151.69 ^{f}	-525.74 ^{ab}
Vietn	10349.47 ^{e}	-1505.03 ^{e}
HDawn	8582.80 ^{g}	-1185.66 ^{d}
PY	11856.78 ^{ab}	-878.43 ^{c}
AM	10277.57 ^{e}	-332.60 ^{a}
Spekko	9957.31 ^{e}	-299.62 ^{a}
Tastic	11614.18 ^{cb}	-756.89 ^{cb}
Tasia	11377.39 ^{c}	-1579.63 ^{e}
RiceL	9072.66 ^{f}	-1624.12 ^{e}
Arroz	10873.98 ^{d}	-344.84 ^{a}
WW	8880.14 ^{fg}	-791.69 ^{c}

[1]Values with the same superscript are not significantly different (P>0.05).

Table 5 Mean RVA results relating to pasting properties for 12 rice samples.

Samples	[1]Mean peak viscosity (cP)	[1]Mean final viscosity (cP)	[1]Mean setback viscosity (cP)
AC	108.33 i	161.33 i	53.00 i
Indian	999.67 c	1919.67 c	920.00 b
Vietn	1291.67 a	1978.00 b	686.33 c
HDawn	1142.67 b	2094 a	951.33 a
PY	617.00 d	733.00 f	116.00 g
AM	466.33 f	561.33 gh	95.00 gh
Spekko	143.67 i	205.67 i	62.00 i
Tastic	94.33 i	149.00 i	54.67 i
Tasia	571.00 e	881.33 d	310.33 d
RiceL	391.33 h	586.33 g	195.00 f
Arroz	437.33 g	530.33 h	93.00 h
WW	559.00 e	812.00 e	253.00 e

[1]Values with the same superscript are not significantly different (P>0.05).

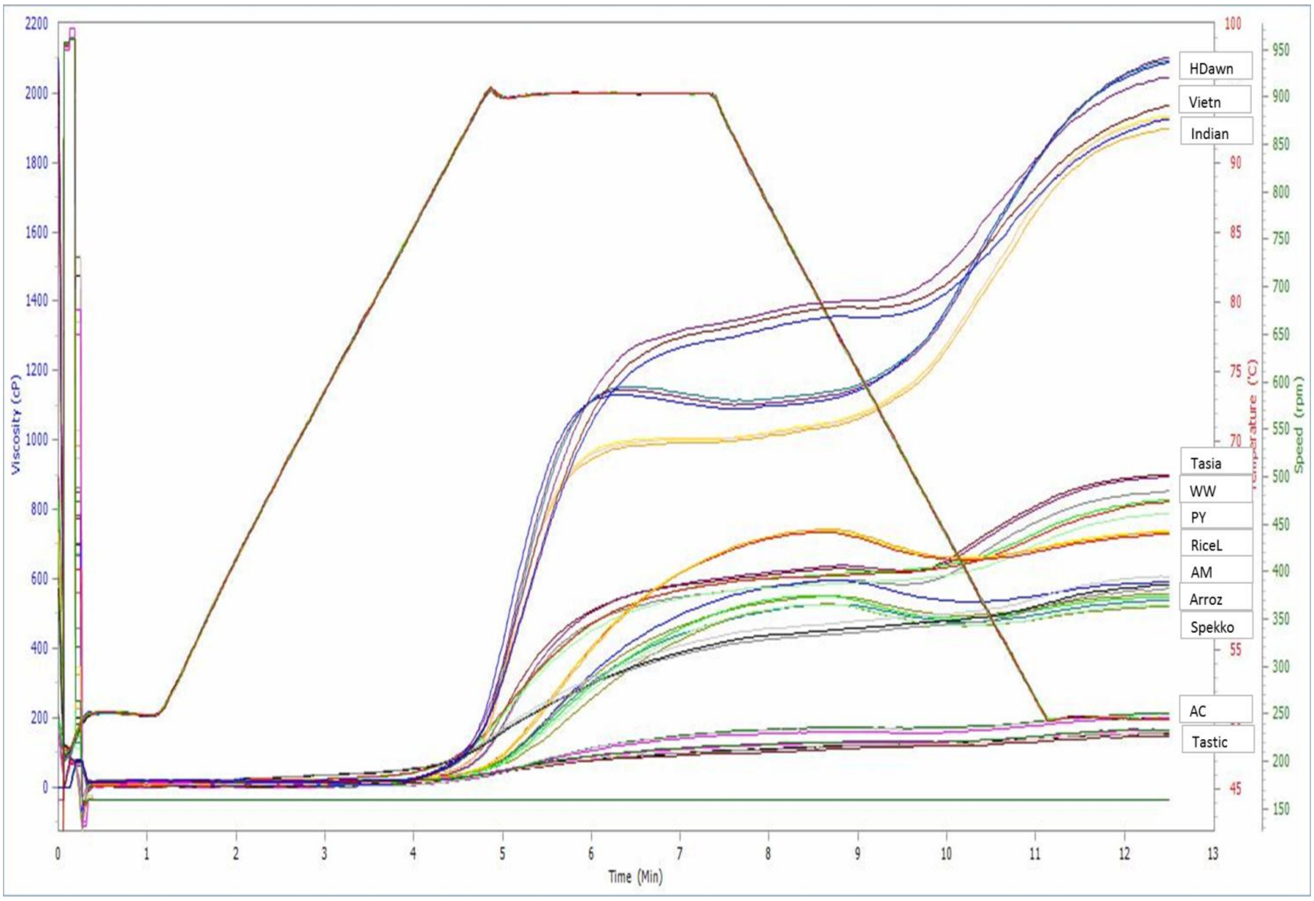


Fig. 5 RVA pasting curves for 12 rice samples.

Table 6 Mean DSC results relating to gelatinisation properties of the 12 rice samples.

Samples	[1]Mean onset (°C)	[1]Mean peak (°C)	[1]Mean offset (°C)	[1]Mean enthalpy (J/g)	Gelatinisation %
AC	79.31 ^{d}	86.03 ^{f}	94.32 ^{c}	0.09 ^{f}	95.95
Indian	76.18 ^{f}	81.64 ^{i}	89.26 ^{f}	0.43 ^{cd}	80.63
Vietn	77.27 ^{fe}	83.62 ^{g}	94.12 ^{c}	0.98 ^{a}	55.86
HDawn	77.56 ^{fe}	82.62 ^{h}	91.01 ^{e}	0.68 ^{b}	69.37
PY	91.26 ^{a}	97.96 ^{b}	104.25 ^{b}	0.21 ^{e}	90.54
AM	79.51 ^{d}	96.59 ^{c}	105.14 ^{a}	0.46 ^{c}	79.28
Spekko	79.12 ^{d}	85.67 ^{f}	92.64 ^{d}	0.39 ^{cd}	82.43
Tastic	81.59 ^{c}	86.75 ^{e}	93.72 ^{c}	0.05 ^{f}	97.75
Tasia	76.30 ^{f}	82.22 ^{h}	91.18 ^{e}	0.25 ^{e}	88.74
RiceL	83.22 ^{b}	87.26 ^{d}	94.27 ^{c}	0.05 ^{f}	97.75
Arroz	79.36 ^{d}	98.75 ^{a}	105.45 ^{a}	0.36 ^{d}	83.78
WW	78.45 ^{de}	86.60 ^{e}	94.32 ^{c}	0.20 ^{e}	90.99
UPB	68.85	75.64	85.47	2.22	0.00

[1]Values with the same superscript are not significantly different (P>0.05).

Table 7 Type of endotherms that may be present in rice.

	Starch gelatinisation (typical)	Annealed starch	Retrograded amylopectin	[1]L-Am I	[2]L-Am II	Retrograded amylose
Endotherm (°C)	65-80	80-85	50-55	90-100	110-120	140-150

[1]Lipid amylose complex 1.

[2]Lipid amylose complex 2.

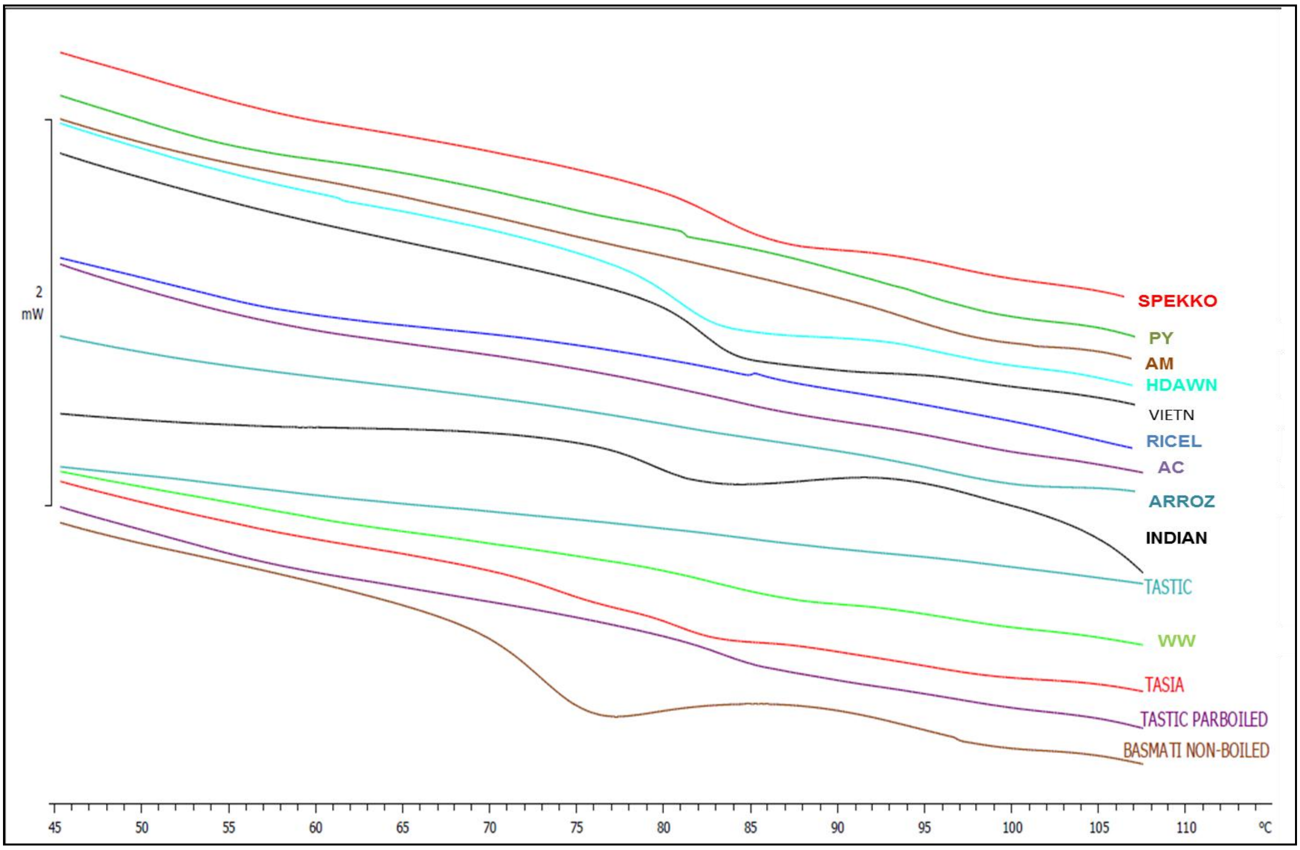


Fig. 6 DSC thermograms of the 12 rice samples including two controls (Tastic parboiled and Basmati non-parboiled).

Table 8 Mean amylose and protein content for the 12 rice samples.

Samples	[1]Mean Amylose (%)	[1]Mean Protein (%)
AC	26.33 [abc]	7.81 [b]
Indian	24.00 [db]	7.87 [b]
Vietn	26.67 [abc]	6.82 [h]
HDawn	25.33 [abc]	7.14 [e]
PY	29.00 [a]	7.37 [c]
AM	27.67 [ab]	7.29 [d]
Spekko	29.00 [a]	7.83 [b]
Tastic	28.33 [a]	8.01 [a]
Tasia	27.33 [abc]	6.68 [i]
RiceL	23.33 [dc]	7.06 [f]
Arroz	28.00 [ab]	6.73 [i]
WW	21.00 [d]	6.92 [g]

[1]Values with the same superscript are not significantly different (P>0.05).

Table 9 Correlation matrix showing Pearson's correlation coefficients for physicochemical measurements.

Physicochemical Variables	Firmness	Stickiness	L* raw	a* raw	b* raw	WI raw	YI raw	L* cooked	a* cooked	b* cooked	WI cooked	YI cooked	Protein
Firmness	1												
Stickiness	-0.08	1											
L* raw	0.27	0.08	1										
a* raw	-0.18	0.16	**-0.80**	1									
b* raw	0.05	0.45	**-0.78**	**0.91**	1								
WI raw	0.04	-0.15	**0.89**	**-0.92**	**-0.98**	1							
YI raw	-0.02	0.18	**-0.86**	**0.93**	**0.99**	**-1.00**	1						
L* cooked	0.04	0.33	0.14	-0.18	-0.02	0.06	-0.05	1					
a* cooked	0.01	-0.02	-0.56	**0.86**	**0.78**	**-0.75**	**0.77**	-0.28	1				
b* cooked	0.16	0.05	-0.67	**0.89**	**0.93**	**-0.89**	**0.91**	-0.28	**0.91**	1			
WI cooked	-0.14	0.02	0.65	**-0.85**	**-0.86**	**0.83**	**-0.85**	0.47	**-0.90**	**-0.98**	1		
YI cooked	0.15	0.03	-0.67	**0.88**	**0.91**	**-0.87**	**0.89**	-0.35	**0.92**	**1.00**	**-0.99**	1	
Protein	0.19	0.35	-0.14	0.36	0.45	-0.37	0.40	0.52	0.49	0.41	-0.27	0.37	1

All values in bold are significantly different from 0 with a 5% significance level. Correlation values denoted in pink are significantly different from 0 ($p < 0.05$), green are $r > 0.5$ and blue are $r < -0.5$. Raw and cooked refers to the uncooked or cooked formats of the rice respectively.

Table 10 Correlation matrix showing Pearson's correlation coefficients for physicochemical measurements (cont.).

Physicochemical Variables	Peak viscosity	Final viscosity	Setback viscosity	Onset	Peak	Offset	Enthalpy	Amylose
Firmness	-0.47	-0.54	-0.59	0.37	0.35	0.36	-0.34	0.69
Stickiness	-0.25	-0.24	-0.22	0.02	0.48	0.42	-0.00	0.27
L* raw	0.53	0.52	0.47	-0.24	0.00	0.07	0.56	0.45
a* raw	**-0.69**	**-0.62**	-0.49	0.18	0.06	-0.05	**-0.58**	-0.17
b* raw	**-0.83**	**-0.79**	**-0.69**	0.16	0.16	0.08	**-0.58**	-0.01
WI raw	**0.78**	**0.74**	**0.66**	-0.19	-0.11	-0.04	**0.60**	0.15
YI raw	**-0.80**	**-0.76**	**-0.66**	0.18	0.13	0.05	**-0.60**	-0.11
L* cooked	0.06	0.08	0.11	0.10	0.01	-0.01	0.16	0.25
a* cooked	**-0.63**	-0.52	-0.35	0.01	-0.25	-0.34	-0.49	-0.04
b* cooked	**-0.83**	**-0.76**	**-0.63**	0.06	0.00	-0.07	**-0.62**	-0.01
WI cooked	**0.78**	**0.71**	**0.60**	-0.03	0.00	0.06	**0.60**	0.006
YI cooked	**-0.81**	**-0.74**	**-0.62**	0.05	0.00	-0.07	**-0.61**	-0.03
Protein	**-0.42**	**-0.29**	**-0.12**	0.14	-0.15	-0.24	**-0.32**	0.22

All values in bold are significantly different from 0 with a 5% significance level. Correlation values denoted in pink are significantly different from 0 ($p < 0.05$), green are $r > 0.5$ and blue are $r < -0.5$. Raw and cooked refers to the uncooked or cooked formats of the rice respectively.

Table 11 Correlation matrix showing Pearson's correlation coefficients for physicochemical measurements (cont.).

Physicochemical Variables	Peak viscosity	Final viscosity	Setback viscosity	Onset	Peak	Endset	Enthalpy	Amylose
Peak viscosity	1							
Final viscosity	**0.98**	1						
Setback viscosity	**0.89**	**0.97**	1					
Onset	-0.28	-0.38	-0.47	1				
Peak	-0.30	**-0.45**	**-0.58**	**0.62**	1			
Endset	-0.21	-0.37	-0.54	0.54	**0.98**	1		
Enthalpy	**0.81**	**0.76**	**0.66**	-0.42	-0.19	-0.07	1	
Amylose	-0.28	-0.34	-0.39	0.31	0.41	0.42	0.07	1

All values in bold are significantly different from 0 with a 5% significance level. Correlation values denoted in pink are significantly different from 0 ($p < 0.05$), green are $r > 0.5$ and blue are $r < -0.5$. Raw and cooked refer to the uncooked or cooked formats of the rice respectively.

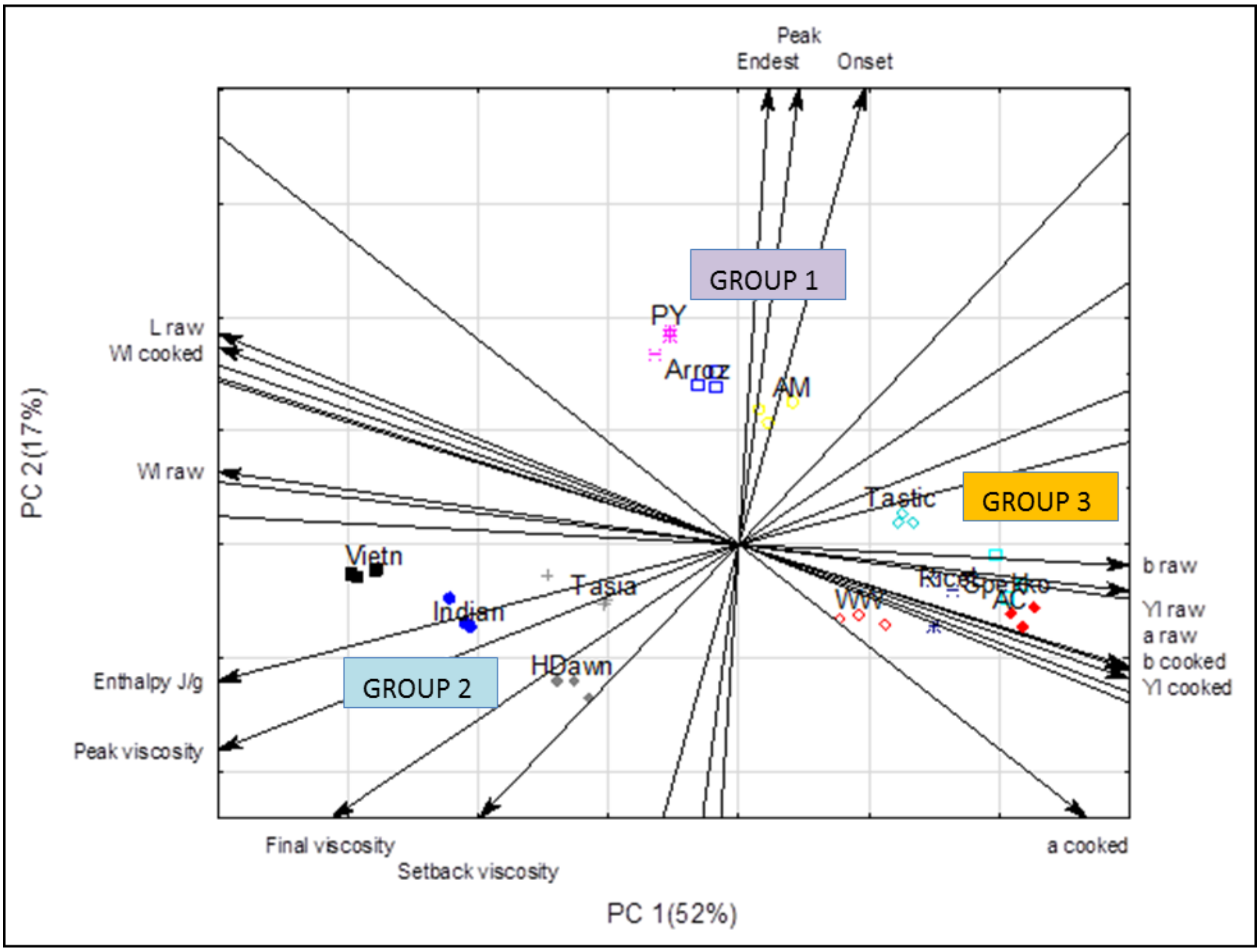


Fig. 7 PCA bi-plot showing the positioning of the 12 long-grain parboiled rice samples and physicochemical measurements, colour (L*, a* and b* value; YI and WI); viscosity (peak, final and setback viscosity); degree of gelatinisation (onset, peak, offendset and enthalpy). Raw and cooked refers to the uncooked or cooked formats of the rice respectively.

Table 12 Correlation matrix showing Pearson's correlation coefficients for physicochemical measurements and DSA profile.

	Physicochemical variables												
Sensory Variables	Firmness	Stickiness	L* raw	a* raw	b* raw	WI raw	YI raw	L* cooked	a* cooked	b* cooked	WI cooked	YI cooked	Protein
A Typical rice R	-0.02	-0.07	**-0.80**	0.47	**0.58**	**-0.68**	**0.64**	-0.04	0.28	0.49	-0.46	0.48	0.27
A Crushed maize kernel R	-0.02	-0.12	-0.36	0.01	0.13	-0.21	0.18	0.27	-0.11	0.05	0.00	0.03	0.27
A Stale/Dusty R	-0.39	-0.40	0.27	-0.14	-0.34	0.34	-0.33	-0.32	0.16	-0.14	0.07	-0.11	-0.22
A Oily R	0.25	0.34	-0.39	0.18	0.35	-0.38	0.36	-0.06	0.03	0.23	-0.22	0.22	0.20
Whiteness intensity R	0.41	-0.10	**0.81**	**-0.91**	**-0.82**	**0.85**	**-0.85**	0.21	**-0.75**	**-0.77**	**0.76**	**-0.77**	-0.29
A Typical cooked rice C	-0.52	0.56	-0.18	0.35	0.18	-0.18	0.20	0.21	-0.03	-0.05	0.09	-0.06	-0.03
A Maize porridge C	-0.06	**0.68**	0.27	-0.21	-0.13	0.18	-0.16	0.48	-0.39	-0.31	0.38	-0.34	0.35
A Toasted C	0.12	0.36	-0.07	0.37	0.43	-0.34	0.38	**0.64**	0.26	0.30	-0.14	0.25	**0.57**
A Buttery C	-0.55	-0.11	**-0.78**	0.42	0.31	-0.47	0.42	0.03	0.04	0.11	-0.09	0.10	-0.15
A Hay C	-0.53	-0.18	**-0.81**	0.48	0.37	-0.52	0.48	-0.25	0.23	0.30	-0.33	0.31	-0.12
T Firmness C	0.43	0.48	-0.44	**0.63**	**0.83**	**-0.75**	**0.78**	0.07	0.55	**0.77**	**-0.69**	**0.74**	0.56
T Springy/Rubbery	0.37	0.47	-0.48	**0.64**	**0.86**	**-0.79**	**0.81**	0.09	**0.57**	**0.79**	**-0.71**	**0.76**	0.53
T Starchy after 5 chews	0.07	-0.49	**0.58**	**-0.61**	**-0.59**	**0.62**	**-0.61**	-0.12	-0.33	-0.45	0.39	-0.43	-0.47

All values in bold are significantly different from 0 with a 5% significance level. Correlation values denoted in pink are significantly different from 0 ($p < 0.05$), green are $r > 0.5$ and blue are $r < -0.5$. The letters "A", "F" and "T" before the sensory attributes denote aroma, flavour and texture, whilst the "C" and "R" refers to the cooked or raw attribute, respectively.

Table 13 Correlation matrix showing Pearson's correlation coefficients for physicochemical measurements and DSA profile (cont.).

	Physicochemical variables							
Sensory Variables	Peak viscosity	Final viscosity	Setback viscosity	Onset	Peak	Endset	Enthalpy	Amylose
A Typical rice R	-0.46	-0.46	-0.43	0.26	0.08	0.04	**-0.60**	-0.46
A Crushed maize kernel R	-0.15	-0.11	-0.05	-0.01	-0.14	-0.16	-0.41	-0.45
A Stale / Dusty R	0.48	0.56	**0.63**	-0.53	-0.70	-0.65	0.49	-0.10
A Oily R	-0.38	-0.48	**-0.57**	0.53	0.53	0.52	-0.29	-0.16
Whiteness intensity R	0.43	0.36	0.25	-0.05	0.02	0.09	0.36	0.42
A Typical cooked rice C	0.04	0.03	0.02	0.29	0.49	0.41	0.08	-0.03
A Maize porridge C	0.14	0.13	0.11	0.17	0.47	0.46	0.17	0.16
A Toasted C	-0.41	-0.32	-0.19	0.06	0.13	0.04	-0.28	0.21
A Buttery C	-0.01	-0.04	-0.07	0.31	0.06	0.01	-0.26	**-0.66**
A Hay C	-0.15	-0.12	-0.08	0.04	-0.17	-0.22	-0.44	**-0.82**
T Firmness C	**-0.88**	**-0.87**	**-0.81**	0.28	0.46	0.40	-0.58	0.32
T Springy/ Rubbery	**-0.91**	**-0.89**	**-0.81**	0.13	0.33	0.28	-0.56	0.30
T Starchy after 5 chews	0.56	0.52	0.44	-0.45	-0.41	-0.28	0.70	0.24

All values in bold are significantly different from 0 with a 5% significance level. Correlation values denoted in pink are significantly different from 0 ($p < 0.05$), green are $r > 0.5$ and blue are $r < -0.5$. The letters "A", "F" and "T" before the sensory attributes denote aroma, flavour and texture, whilst the "C" and "R" refers to the cooked or raw attribute, respectively.

Table 14 Correlation matrix showing Pearson's correlation coefficients for physicochemical measurements and DSA profile (cont.).

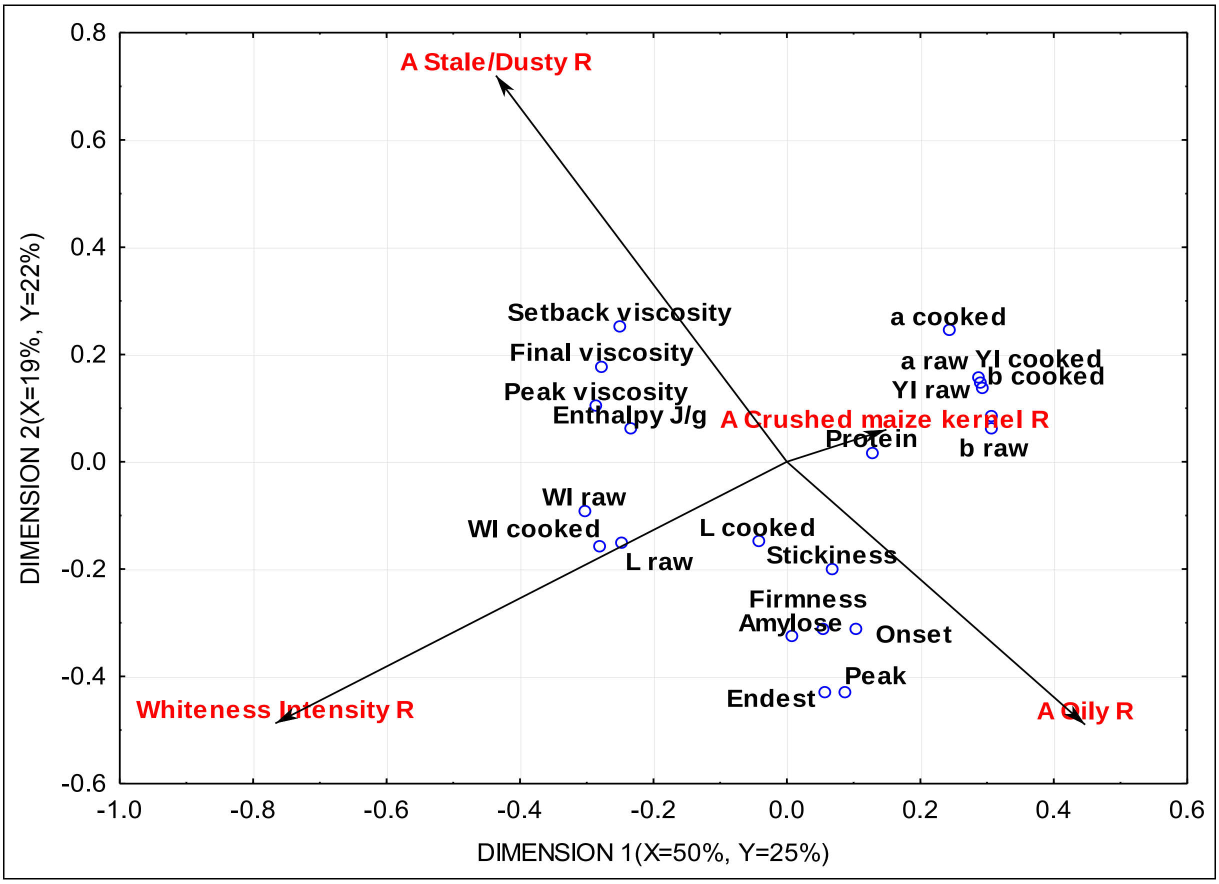
	Physicochemical variables												
Sensory Variables	Firmness	Stickiness	L* raw	a* raw	b* raw	WI raw	YI raw	L* cooked	a* cooked	b* cooked	WI cooked	YI cooked	Protein
F Typical rice C	**-0.58**	0.25	-0.11	0.08	-0.14	0.07	-0.08	0.14	-0.17	-0.27	0.28	-0.26	-0.06
Whiteness Intensity C	0.12	-0.12	**0.78**	**-0.90**	**-0.91**	**0.92**	**-0.92**	0.16	**-0.80**	**-0.88**	**0.85**	**-0.87**	-0.42
Grain-to-grain stickiness C	-0.32	**-0.71**	0.31	-0.54	**-0.66**	**0.58**	**-0.61**	-0.17	-0.40	-0.56	0.48	-0.53	**-0.61**
Swollen/Plump C	-0.17	-0.53	**0.58**	**-0.71**	**-0.80**	**0.77**	**-0.78**	-0.04	-0.48	**-0.67**	**0.61**	**-0.65**	-0.47

All values in bold are significantly different from 0 with a 5% significance level. Correlation values denoted in pink are significantly different from 0 ($p < 0.05$), green are $r > 0.5$ and blue are $r < -0.5$. The letters "A", "F" and "T" before the sensory attributes denote aroma, flavour and texture, whilst the "C" and "R" refers to the cooked or raw attribute, respectively.

Table 15 Correlation matrix showing Pearson's correlation coefficients for physicochemical measurements and DSA profile (cont.).

	Physicochemical variables							
Sensory Variables	Peak viscosity	Final viscosity	Setback viscosity	Onset	Peak	Endset	Enthalpy	Amylose
F Typical rice C	0.28	0.32	0.36	0.08	0.05	-0.04	-0.10	**-0.61**
Whiteness Intensity C	**0.62**	**0.57**	0.47	-0.15	-0.08	-0.02	0.43	0.14
Grain-to-grain stickiness C	**0.79**	**0.76**	**0.68**	-0.37	-0.52	-0.41	**0.63**	-0.31
Swollen /Plump C	**0.76**	**0.77**	**0.73**	-0.49	**-0.59**	-0.51	**0.61**	-0.13

All values in bold are significantly different from 0 with a 5% significance level. Correlation values denoted in pink are significantly different from 0 ($p < 0.05$), green are $r > 0.5$ and blue are $r < -0.5$. The letters "A", "F" and "T" before the sensory attributes denote aroma, flavour and texture, whilst the "C" and "R" refers to the cooked or raw attribute, respectively.



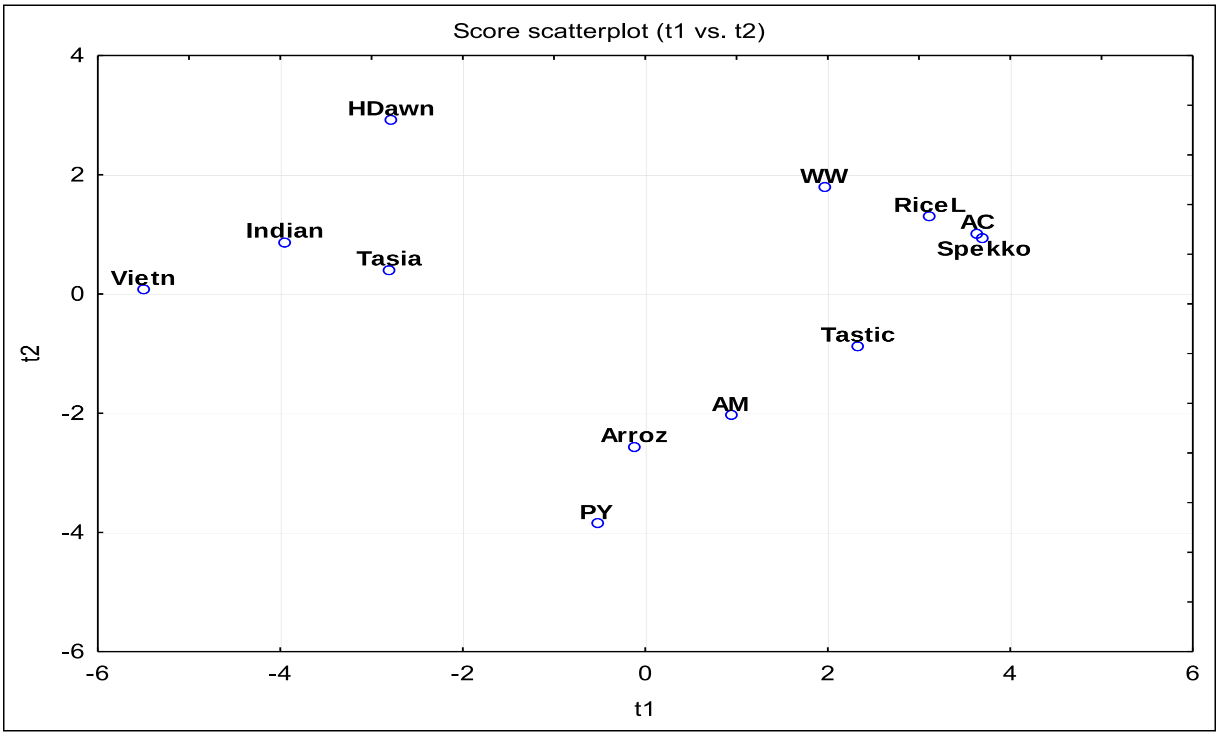
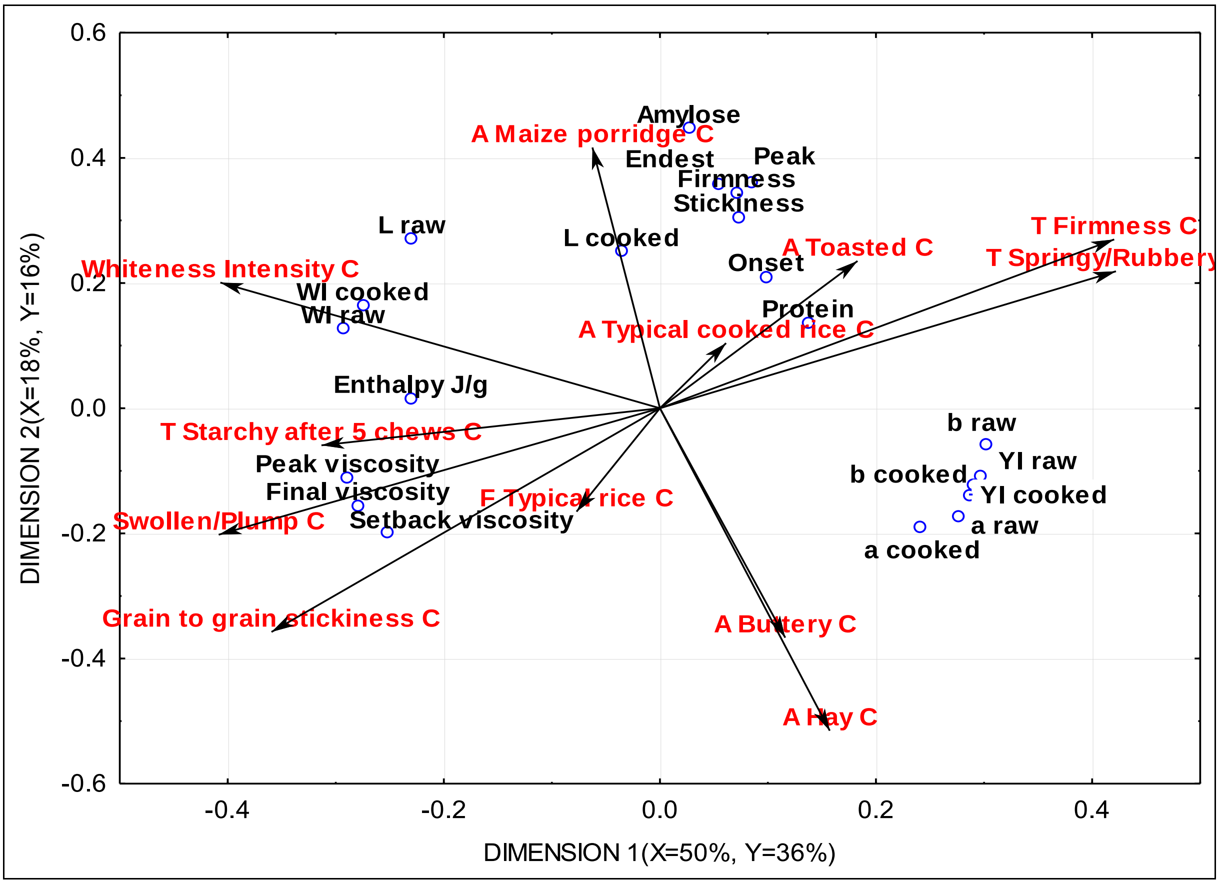


Fig. 8a) Partial least squares regression (PLS) loadings plot indicating the correlation between physicochemical measurements **(Black)** and the raw sensory attributes **(Red); b)** Corresponding scores plot indicating the positions of the 12 rice samples in relation to the PLS plot. The letters “A”, “R” refer to aroma and raw, respectively.



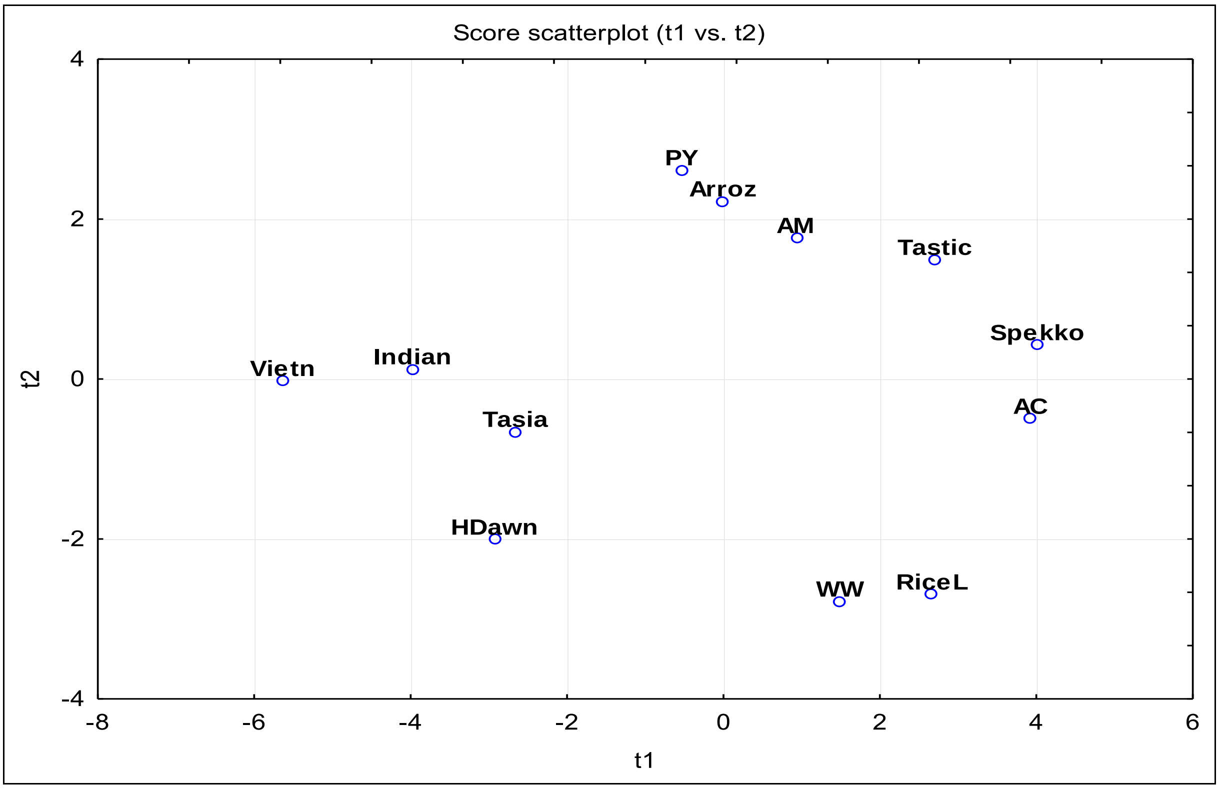
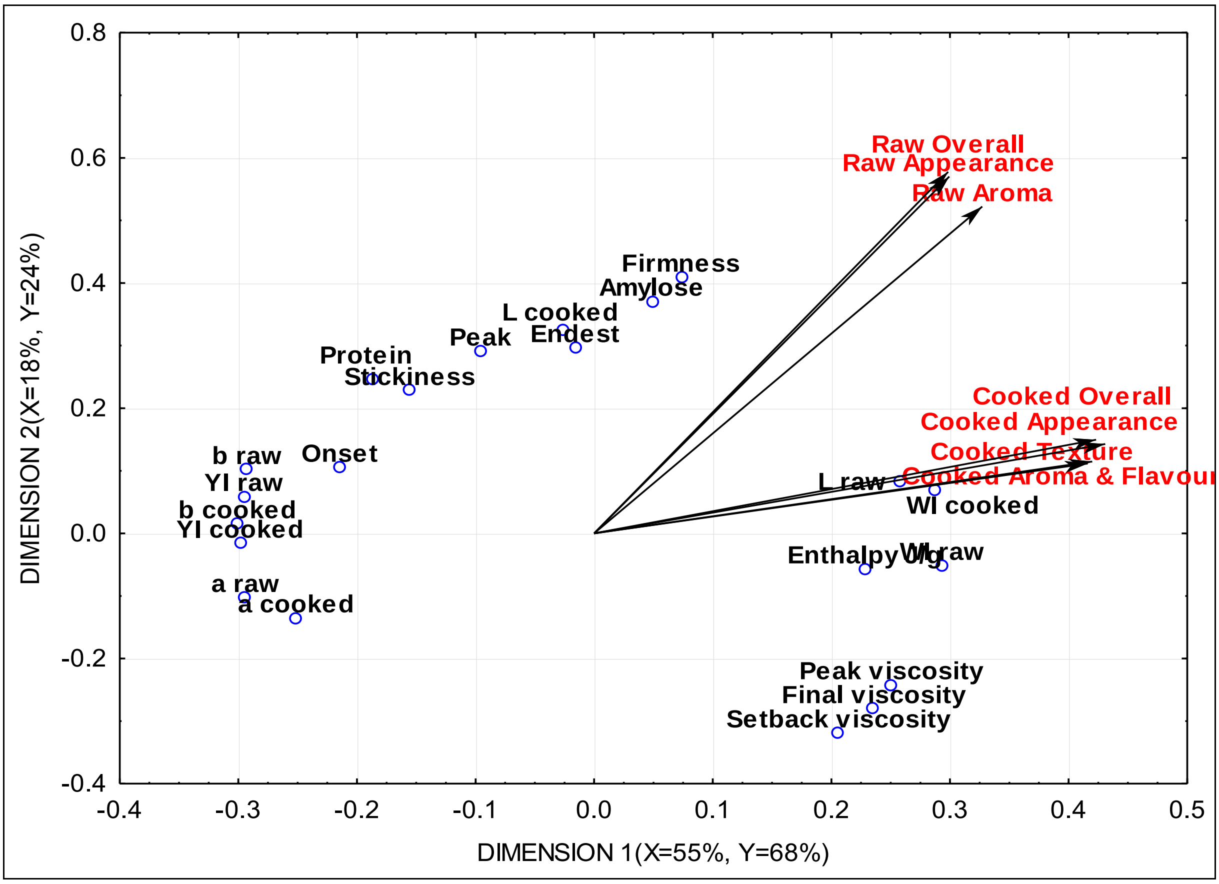


Fig. 9a) Partial least squares regression (PLS) loadings plot indicating the correlation between physicochemical measurements **(Black)** and the cooked sensory attributes **(Red)**; **b)** Corresponding scores plot indicating the positions of the 12 rice samples in relation to the PLS plot. The letters “A”, “C”, “T” and “F”, refer to aroma, cooked, texture and flavour, respectively.



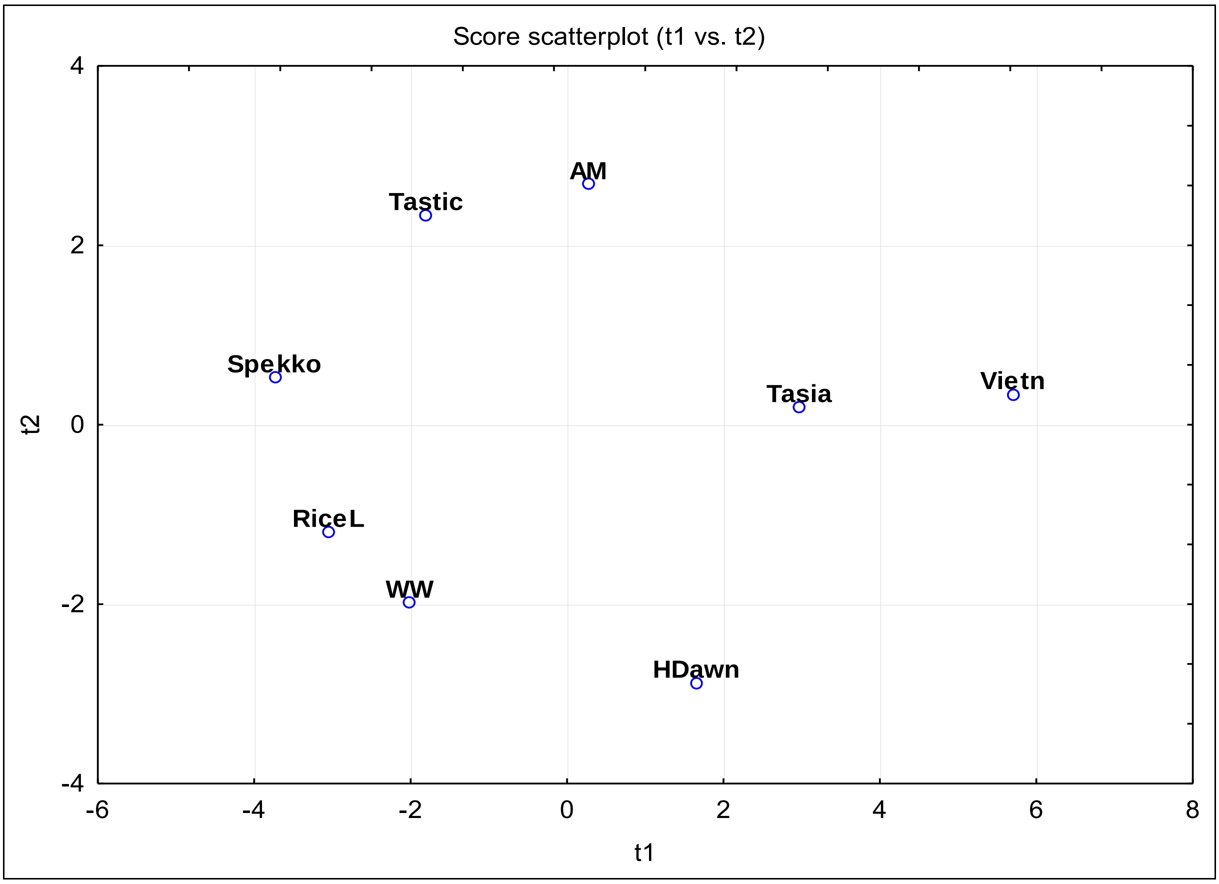


Fig. 10a) Partial least squares regression (PLS) loadings plot indicating the overall correlation between physicochemical measurements **(Black)** and the consumer preference **(Red), b)** Corresponding scores plot indicating the positions of the 8 rice samples in relation to the PLS plot.

Table 16 Correlation matrix showing Pearson's correlation coefficients for physicochemical measurements and consumer liking for 8 rice samples.

	Physicochemical Variables												
Liking Variables	Firmness	Stickiness	L* raw	a* raw	b* raw	WI raw	YI raw	L* cooked	a* cooked	b* cooked	WI cooked	YI cooked	Protein
Raw appearance	**0.78**	-0.01	0.69	-0.78	**-0.48**	0.56	-0.55	0.42	-0.70	-0.60	**0.70**	-0.64	-0.04
Raw aroma	**0.73**	-0.13	0.63	**-0.84**	-0.54	0.59	-0.59	0.36	**-0.83**	-0.70	**0.77**	**-0.73**	-0.20
Raw overall	**0.80**	0.00	**0.71**	**-0.78**	-0.48	0.57	-0.56	0.39	-0.69	-0.60	0.69	-0.63	-0.03
Cooked appearance	0.37	-0.44	**0.81**	**-0.94**	**-0.87**	**0.88**	**-0.89**	-0.05	**-0.83**	**-0.90**	**0.87**	**-0.90**	-0.57
Cooked aroma & flavour	0.32	-0.54	0.68	**-0.93**	**-0.86**	**0.83**	**-0.85**	-0.11	**-0.91**	**-0.91**	**0.87**	**-0.91**	**-0.70**
Cooked texture	0.30	-0.57	**0.70**	**-0.89**	**-0.85**	**0.83**	**-0.85**	-0.06	**-0.87**	**-0.90**	**0.87**	**-0.90**	-0.64
Cooked overall	0.29	-0.44	**0.72**	**-0.92**	**-0.85**	**0.84**	**-0.85**	-0.08	**-0.92**	**-0.92**	**0.88**	**-0.91**	-0.63

All values in bold are significantly different from 0 with a 5% significance level. Correlation values denoted in pink are significantly different from 0 ($p < 0.05$), green are $r > 0.5$ and blue are $r < -0.5$.

Table 17 Correlation matrix showing Pearson's correlation coefficients for physicochemical measurements and consumer liking (cont.).

	Physicochemical Variables							
Liking Variables	Peak viscosity	Final viscosity	Setback viscosity	Onset	Peak	Endset	Enthalpy	Amylose
Raw appearance	0.16	0.08	-0.04	-0.35	0.14	0.32	0.42	**0.71**
Raw aroma	0.24	0.14	-0.01	-0.34	0.16	0.36	0.41	0.54
Raw overall	0.15	0.07	-0.04	-0.35	0.15	0.33	0.39	**0.71**
Cooked appearance	0.65	0.59	0.47	-0.65	-0.18	0.07	0.67	0.35
Cooked aroma & flavour	0.64	**0.56**	0.43	-0.55	-0.09	0.15	0.57	0.16
Cooked texture	0.66	0.59	0.48	-0.48	-0.09	0.15	0.58	0.21
Cooked overall	0.67	0.59	0.46	-0.54	0.01	0.26	0.62	0.20

All values in bold are significantly different from 0 with a 5% significance level. Correlation values denoted in pink are significantly different from 0 ($p < 0.05$), green are $r > 0.5$ and blue are $r < -0.5$.

CHAPTER 7

GENERAL DISCUSSION AND CONCLUSIONS

This study set out to explore consumer preferences for long-grain parboiled rice and to determine the sensory characteristics that drive consumer liking. Furthermore, the study aimed to compile preliminary sensory and physicochemical product specifications for long-grain parboiled rice based on these consumer preferences. With rice imports increasing each year, the commercial rice market in South Africa is becoming more competitive and consequently optimising the sensory characteristics of long-grain parboiled rice, to ensure increased consumption, demands identifying and meeting consumer sensory needs.

This study firstly detailed the full sensory profile of 12 long-grain parboiled rice samples using extensive descriptive sensory analyses (DSA). Five samples were from South East Asia (Tasia, Spekko, Tastic, Aunt Caroline (AC)); three from South America (PY, Arroz, Americano (AM)); two from India (Indian, Harvest Dawn (HDawn)); and two from North America (Riceland (RiceL) and Woolworths (WW)). Consumer acceptance of eight selected long-grain parboiled rice samples with dissimilar sensory profiles were also determined using the target consumers in Gauteng, Western Cape and KwaZulu-Natal provinces. In addition, consumer attitudes towards and opinions of long-grain parboiled rice were explored through the focus group technique. Analysis associated with physicochemical properties was also conducted and related to both sensory attributes and consumer preference. Partial least squares (PLS) regression was performed on the descriptive sensory and consumer liking data. The advantage of this technique lies in objectively characterising the sensory attributes of long-grain parboiled rice via descriptive sensory analysis (DSA) and relating this data to the preference ratings for the long-grain parboiled rice samples obtained from the panel. Since PLS can manage multiple dependent variables in the same model, physicochemical measurements were also included in the analysis. Consequently, areas where long-grain parboiled rice can be optimised to satisfy consumer sensory requirements were identified.

Significant research findings

Descriptive sensory analysis (DSA) established the full sensory profile of the long-grain parboiled rice samples and a sensory lexicon consisting of 26 attributes was developed which included descriptors for aroma, flavour, texture and appearance. Consumer panel results indicated that consumers preferred the raw and cooked sensory characteristics associated with the rice samples of Vietn, Tasia and AM. Consumers were selected from the Johannesburg, Cape Town and

Durban metropoles and were all female, between the ages of 25-55 years and from the Living Standard Measure (LSM) 6-9 (Anon., 2012). The preferred samples were mainly characterised in terms of raw rice as having a high “whiteness intensity”. The preferred cooked rice sample appearances were described as being high in “whiteness intensity”, having a slight “grain-to-grain stickiness”, as well as a “swollen/plump” appearance. Texture is usually an important driver of cooked rice quality and can be defined as ‘‘the sensory and functional manifestation of the structural, mechanical and surface properties of foods detected through the senses of vision, hearing, touch and kinesthetics’’ (Szczesniak, 2001). The texture attributes described the cooked rice as having a slight “stickiness in the mouth” and being slightly “starchy after 5 chews”. The texture can further be described as being medium in “firmness” and not “springy/rubbery”. Sensory attributes of high “firmness”, “springy/rubbery”, as well as low “whiteness intensity” were rejected by consumers. These appearance and texture attributes characterised the samples WW, RiceL, Tastic, HDawn and Spekko. Thus it was determined that the consumer preference for raw rice is driven primarily by appearance, specifically colour, while the preference for cooked rice is driven primarily by texture and appearance, and interestingly enough not rice flavour *per se*. A preliminary sensory quality specification (Table 1) was compiled using the mean intensity values from the attributes that drive liking for the most preferred samples (Vietn, Tasia and AM).

The focus group study investigated consumers’ general opinions and attitudes toward long-grain parboiled rice, focusing specifically on determining whether there is a trade-off between the various quality drivers. Results indicated that long-grain parboiled rice consumers were not homogenous when it comes to the trade-off between the different drivers of liking. The trade-offs were mainly influenced by ethnicity rather than demographic area or LSM measures. Non-intrinsic factors, namely brand and price, also had a significant role to play in consumer purchase patterns.

Additional to this study the descriptive sensory analysis technique was compared to the sorting technique to determine the suitability of sorting as a rapid sensory profiling method within the industry environment. Results indicated that the sorting technique can be utilised as a broad-based alternative for sensory profiling of rice quality in industry, especially when answers are required quickly during competitor and procurement comparisons.

Physicochemical drivers of liking for raw rice were determined to be the colour measurements, specifically the Lightness (L*-value) and Whiteness Index (WI). Physicochemical drivers of liking for cooked rice included the colour measurement WI, enthalpy (indication of degree of gelatinisation), and peak, final and setback viscosity (indication of cooked product texture). Preliminary physicochemical quality specifications (Table 2) have been compiled using the mean minimum and maximum values associated with the key physicochemical drivers for the most preferred samples (Vietn, Tasia and AM).

Table 1 Proposed sensory quality specifications for long-grain parboiled rice.

Sensory attributes	Measurement	Description	Minimum and maximum intensity values on 100-point intensity scale[1]
		Sensory quality specifications	
Raw attributes	Whiteness Intensity	Degree of whiteness	68-75
Cooked attributes	Whiteness Intensity	Degree of whiteness	86-89
	Stickiness in mouth	The amount of stickiness experienced in the inside of the mouth	6-7
	Swollen/plump	Degree to which grains are swollen/plump	77-82
	Starchy after 5 chews	Starchy mouthfeel (floury) whilst / after chewing	10-17
	Grain to grain stickiness	Visual adhesiveness of grains with one another	26-34

[1]Intensity scale with 0 = low intensity; 100 = high intensity.

Table 2 Proposed physicochemical quality specifications for long-grain parboiled rice.

	Measurement and unit	Description	Instrument	Minimum and maximum measured values
		Physicochemical quality specification		
Raw rice	L* value	Lightness		>65<68
	WI_{CIE}	Whiteness Index	Colorimeter	>-94<-121
	YI_{E313}	Yellowness Index		>39<45
Cooked rice	WI_{CIE}	Whiteness Index	Colorimeter	>-3 – <-22
	YI_{E313}	Yellowness Index		>17<22
	Peak viscosity (cP)	Measurements of viscosity		>466<1292
	Final viscosity (cP)		RVA	>561<1978
	Setback viscosity (cP)			>95<687
	Enthalpy (J/g)	Change in energy	DSC	>0.25<0.98
	Gelatinisation (%)	Calculation making use of enthalpy values (raw and parboiled)	DSC	>56<89
	Amylose (%)		Spectrophotometer	>26<28

Processing parameter recommendations

Understanding the effect of processing parameters on the quality of parboiled rice and how these influence the physicochemical changes which occur during parboiling, is fundamental to the production of parboiled rice with a consistent quality. Diverse differences of the parboiling process yield rice with different material properties and this may challenge consumer preference for the product (Oli *et al*., 2014)

In order to produce long-grain parboiled rice, which is of preferred quality, as indicated by the consumer, the various steps implemented during processing must be optimised. However, the lack of processing information of the samples, used in this study, has made it difficult to propose processing parameters that will yield the desired final quality, as preferred by the consumer. In order to overcome this limitation, the literature, dealing specifically with the effects of different processing parameters in the parboiling process and their resultant quality characteristics, was consulted and used to draft a preliminary processing guideline.

There are many variations of the traditional parboiling methods, depending on the area and scale of the operation (Araullo *et al*., 1976). Key factors have been identified that impact on the material changes, as a result of the changes in chemical and physical properties of the rice kernels during the parboiling process. The first factor is the diffusion of water and other compounds into and out of the rice kernel during the soaking step, dehydration during drying, and rehydration when rice is cooked prior to consumption. The second factor includes starch gelatinisation and protein denaturation during heating, which is influenced by moisture content, temperature and time of exposure. The last factor is that of starch retrogradation after the heat treatment process (Oli *et al*., 2014).

Bhattacharya and Subba Rao (1966) found that the combined severity of the heat treatment during the soaking and steaming steps, were the main reasons which affected the cooking quality and colour of parboiled rice. They found that soaking temperatures of up to 60ºC appeared to have only a slight discolouration effect on the rice colour, but as soon as the temperature increased above 60ºC, the rice became more discoloured. This discolouration was more pronounced if the rice was soaked for long periods of time. Similarly, as soon as the time and pressure of steaming increased, the discolouration of the rice increased. Furthermore, Bhattacharya and Subba Rao (1966) found that the colour-inducing effect of high temperature soaking is more than that of severe steaming. To produce a rice which is soft cooking and white in colour, soaking should be done at relatively low temperatures (below 70ºC) for the shortest time possible and the rice should be exposed to the minimum amount of steaming and quick cooling of the paddy. To produce hard rice, the reverse processing conditions will have to be employed (Bhattacharya & Subba Rao, 1966). Himmelsbach *et al.* (2008) investigated the effects of variable soaking temperatures (30, 50, 70 and 90ºC) and steaming times at each soaking temperature (4, 8 and 12 min, respectively) on medium to long-grain rice. They analysed the rice pasting properties and the degree of gelatinisation at each time and temperature combination. Their results indicated that soaking at 90ºC and subsequent steaming for 12 min yielded rice that was significantly more gelatinised (gelatinisation = 67.6%) than the remaining soaking and steaming combinations. From these two studies it is evident that there is a trade-off between achieving the desired colour and degree of gelatinisation. The soaking temperature of 70ºC and steaming for 12 min resulted in a gelatinisation of 60.50%, which may be a good point of departure for establishing parboiling processing parameters.

It is important to keep in mind that the primary objective of parboiling is to improve the rice quality and obtain higher milling yield; the processing parameters used to achieve rice that meets consumer preference still has to be economically viable in terms of the milling yield (Parnsakhorn & Noomhorm, 2008). Marshall *et al*. (1993) found, upon investigating the two methods of determining the degree of gelatinisation, that the milling yield reached a maximum at about 40% gelatinisation. This is, however, different from the findings observed by Priestly (1976), who found that rice had to be 100% gelatinised to achieve the maximum milling yield. It is important that optimum processing parameters, satisfying both milling yield and consumer preference, be established.

Careful varietal selection for parboiling is crucial, since the effect of processing was found to be identical in terms of the extent of change between different varieties tested; in other words, the original varietal difference was carried over nearly unchanged after processing and all varieties advanced to a measureable extent in a particular direction (Bhattacharya, 2011). Other factors that could influence rice, as the substrate for parboiling, are agronomic practices, as well as the climate and soil quality to which the rice plant was subjected.

In conclusion, the results of this thesis provided insight into rice as a commodity that is not cultivated in South Africa. Additionally, with the aim of increasing consumer consumption of long-grain parboiled rice, these results offered an understanding of consumer preferences and a preliminary final product specification to satisfy these sensory requirements. It is, however, recommended that, when conducting future research and development, possible consumer segmentation, based on socio-demographic influences, should be investigated. It is further recommended that consumer in-home testing of the identified preferred rice samples be explored, since there are many variables in rice preparation that can adversely affect the overall consumer acceptability.

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