Chapter 2. Rice (*Oryza sativa*)

This chapter deals with the composition of rice (Oryza sativa). It contains elements that can be used in a comparative approach as part of a safety assessment of foods and feeds derived from new varieties. Background is given on rice industry terminology, cultivated species, production and consumption worldwide, processing from paddy rice to brown, milled or parboiled rice products for human consumption, and feed use of by-products. Appropriate varietal comparators and characteristics screened by rice breeders are presented. Nutrients in paddy rice, brown rice, milling fractions, whole plant and straw, as well as main anti-nutrients, toxicants and putative allergens are then detailed. The final sections suggest key constituents for analysis in rice matrices of new varieties, for food use and for feed use.

This chapter was prepared by the OECD Working Group for the Safety of Novel Foods and Feeds, with Japan as the lead country and expertise from other stakeholders including the International Rice Research Institute (IRRI), Philippines. It updates and replaces the original publication on rice composition considerations issued in 2004 (contained in Volume 1) and was initially issued in August 2016. FAOSTAT data on cereals production, including Figure 2.2, and IRRI World Rice Statistics data on rice production, trade and consumption, including Tables 2.2 and 2.4, have been updated.

Terminology

A number of technical and scientific terms that are specific to the rice industry are used in this document. In order to facilitate common understanding, these terms and their definitions are listed in Table 2.1.

Table 2.1. Definitions in this document

Term	Synonym(s)	Definition
Bran		Germ and several histologically identifiable soft outer layers (pericarp, seed coat, nucellus and aleurone layer)
Broken rice		Milled broken rice grains, subdivided into second heads (½ - ¾), screenings (¼ - ½) and brewer's rice (< ¼) by the grain length, compared with that of the whole rice
Brown rice	caryopsis, cargo rice, hulled rice, husked rice, dehulled rice, dehusked rice, unpolished rice	Paddy rice from which the hull only has been removed; the process of hulling and handling may result in some loss of bran
Endosperm		Starchy tissue covered by the aleurone layer; divided into two regions, the subaleurone layer and the central core region containing mainly starch
Germ	embryo	The part consisting of scutellum, plumule, radicle and epiblast
Glutinous rice	waxy rice, sticky rice	Rice of which amylose content is less than 5%
Head rice	head yield	Milled whole rice kernels, exclusive of broken rice that is smaller than ¾ of the grain length of the whole rice
Hull	husk, shell, chaff	Outermost layer of paddy rice
Hulling	dehulling, husking, dehusking, shelling	Removal of the hull from paddy rice
Milled rice	white rice	Rice grain with removed germ and outer layer such as pericarp, seed coat and a part of aleurone layer by milling
Milling	scouring, whitening	Removal of all or most of the bran to produce the milled rice that is white
Paddy rice	rice grain, rough rice	Rice grain after threshing and winnowing; retains its hull
Parboiled rice		Hulled or milled rice processed from paddy or hulled rice which has been soaked in water and subjected to a heat treatment so that the starch is fully gelatinized, followed by a drying process
Polished rice		Rice grain with removed outer layer by polishing of milled rice
Polishing		Abrasive removal of traces of bran on the surface of milled rice to give a smoother finish
Polishings	polish	The by-product from polishing rice, consisting of the inner bran layers of the kernel with part of the germ and a small portion of the starchy interior

Figure 2.1. Rice plants

Source: Courtesy of the IRRI, licenced under CC BY-SA.

Background

Cultivated rice species

Most of the rice varieties grown in the world belong to the species *Oryza sativa* which has its origin in Asia. Another species grown in western Africa, *Oryza glaberrima*, is considered to have been domesticated in the Niger river delta. Varieties of the species *Oryza glaberrima* are cultivated in limited regions and detailed production data are scarcely available. For these reasons, this document deals only with *Oryza sativa* that occupies the great majority of the rice production and consumption in the world.

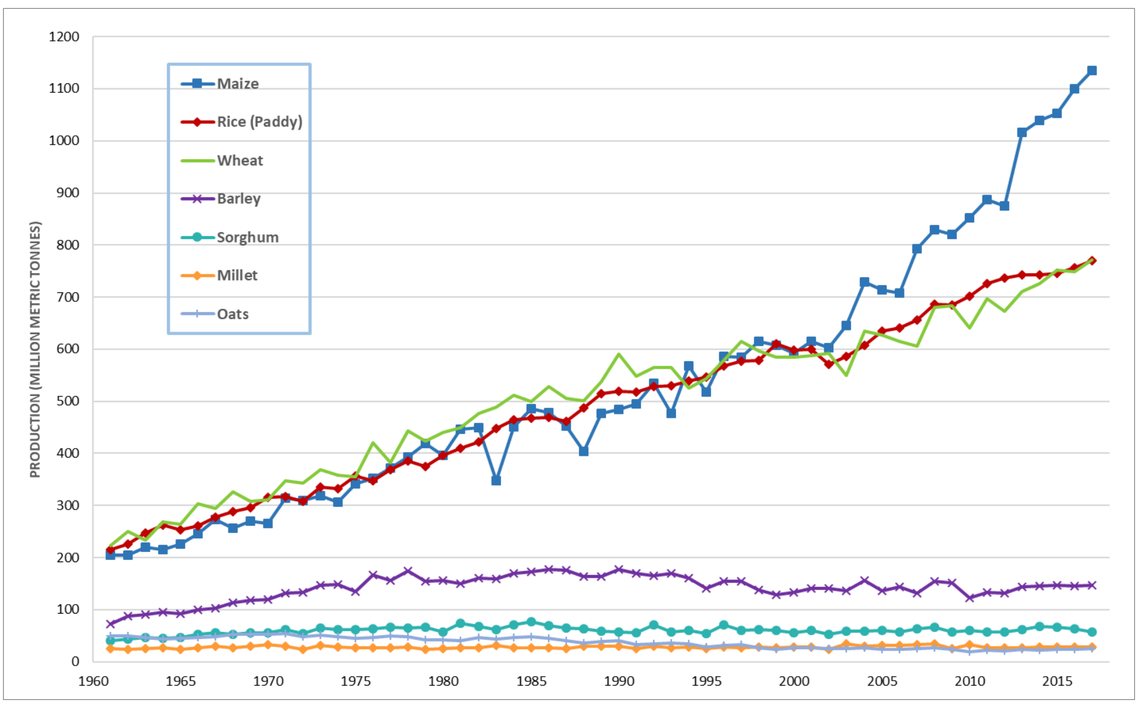
Oryza sativa has two types, indica and japonica, which account for almost all global rice production. Indica is the dominant type, estimated to account for more than 80% of global rice production. It is mostly grown in the tropics and subtropics. Indica rice cooks fluffy, dry and separate, and the grain is usually more slender than that of japonica rice. Japonica rice is typically grown in more temperate areas such as Australia, northern China, Japan and Europe. It cooks moist and clingy. It accounts for 15% of global rice production and typically achieves higher yields than indica. Aromatic rice varieties, primarily, basmati and jasmine, account for 1% of total world rice production. These varieties are noted for their fragrant taste and smell, contributed primarily by the presence of 2-acetyl-1-pyrroline. Glutinous rice varieties of both indica and japonica types account for most of the remainder of world rice production.

Further description on the rice taxonomy, centre of origin and diversity, identification among rice species and groups, reproductive biology, intraspecific and interspecific crosses, and ecology can be found in the Consensus Document on the Biology of *Oryza sativa* (Rice) (OECD, 1999).

Production and consumption

Rice is cultivated in more than 100 countries around the world, being one of three major staple crops after maize and with a total production similar to wheat (Figure 2.2). Rice is a basic food for about half of the world's population. In 2017, its global cropping area covered about 161 million hectares and the production of paddy rice exceeded 729 million metric tonnes (Table 2.2). Asia is the main rice-producing region by far, totalling more than 93% of paddy rice harvested globally (IRRI World Rice Statistics, 2019). The country with the highest production is the People's Republic of China, representing 29% of the total share in 2017, followed by India (23%). Yield (tonnes/hectare) has rapidly increased since the second half of the 1960s as the semi-short (short-stem) and high-yield varieties became widespread. Rice is mostly consumed in each producing country. The world trade amount of rice was approximately 49 million metric tonnes in 2017 (Table 2.3), which represented 10% of the world production of milled rice.

Figure 2.2. Production of major staple cereal crops in the world, 1961-2017



Note: Aggregate may include official, semi-official, estimated or calculated data.
Source: FAOSTAT (2019), *Online database: Production/ Crops: Barley, Maize, Millet, Oats, Rice (paddy), Sorghum, Years 1961 to 2017*, http://www.fao.org/faostat/ (accessed on 10 July 2019).

Table 2.2. World production and main producing countries of paddy rice in 2017

Rank	Country	Production (million metric tonnes)
1	China (People's Republic of)	208.6
2	India	165.0
3	Indonesia	58.3
4	Bangladesh	49.0
5	Viet Nam	45.7
6	Thailand	30.9

Rank	Country	Production (million metric tonnes)
7	Myanmar	20.6
8	Philippines	19.5
9	Brazil	11.9
10	Pakistan	11.3
11	Japan	10.4
12	Cambodia	8.9
13	United States	8.1
14	Egypt	6.2
15	Nigeria	6.0
	World	**729.1**

Source: IRRI World Rice Statistics (2019), *Online database: Paddy Rice Production in 2017,* http://ricestat.irri.org:8080/wrsv3/entrypoint.htm (accessed on 10 July 2019).

Table 2.3. World rice exports and imports in 2017

In million metric tonnes

Rank	Exporting country	Exports	Importing country	Imports
1	India	12.8	China (People's Republic of)	5.5
2	Thailand	10.5	Nigeria	2.6
3	Viet Nam	6.8	Indonesia	2.0
4	Pakistan	4.0	Côte d'Ivoire	1.5
5	Myanmar	3.5	Philippines	1.4
6	United States	3.2	Iran	1.3
7	China (People's Republic of)	1.6	Saudi Arabia	1.3
8	Cambodia	1.3	Bangladesh	1.2
9	Uruguay	0.9	Senegal	1.2
10	Brazil	0.9	Iraq	1.1
	World (Total)	**48.7**	**World (Total)**	**46.0**

Source: IRRI World Rice Statistics (2019), *Online database: Rice Export and Import Quantities in 2017*; http://ricestat.irri.org:8080/wrsv3/entrypoint.htm (accessed on 10 July 2019).

Rice consumption worldwide is shown in Table 2.4, with the highest per capita consumption being reported for Asia. Rice accounts for 19% of global caloric intake and the values are even higher in Asia (IRRI World Rice Statistics, 2019).

Table 2.4. Production and consumption of milled rice by continent/region

Region	Production* (million metric tonnes)	Consumption** (kg/capita/year)
Asia	439.6	77.8
Africa	20.6	23.9
South America	16.7	28.7
North and Central America	7.6	10.7
Europe	3.3	4.6
Oceania	0.6	13.4
World	**488.3**	**54.0**

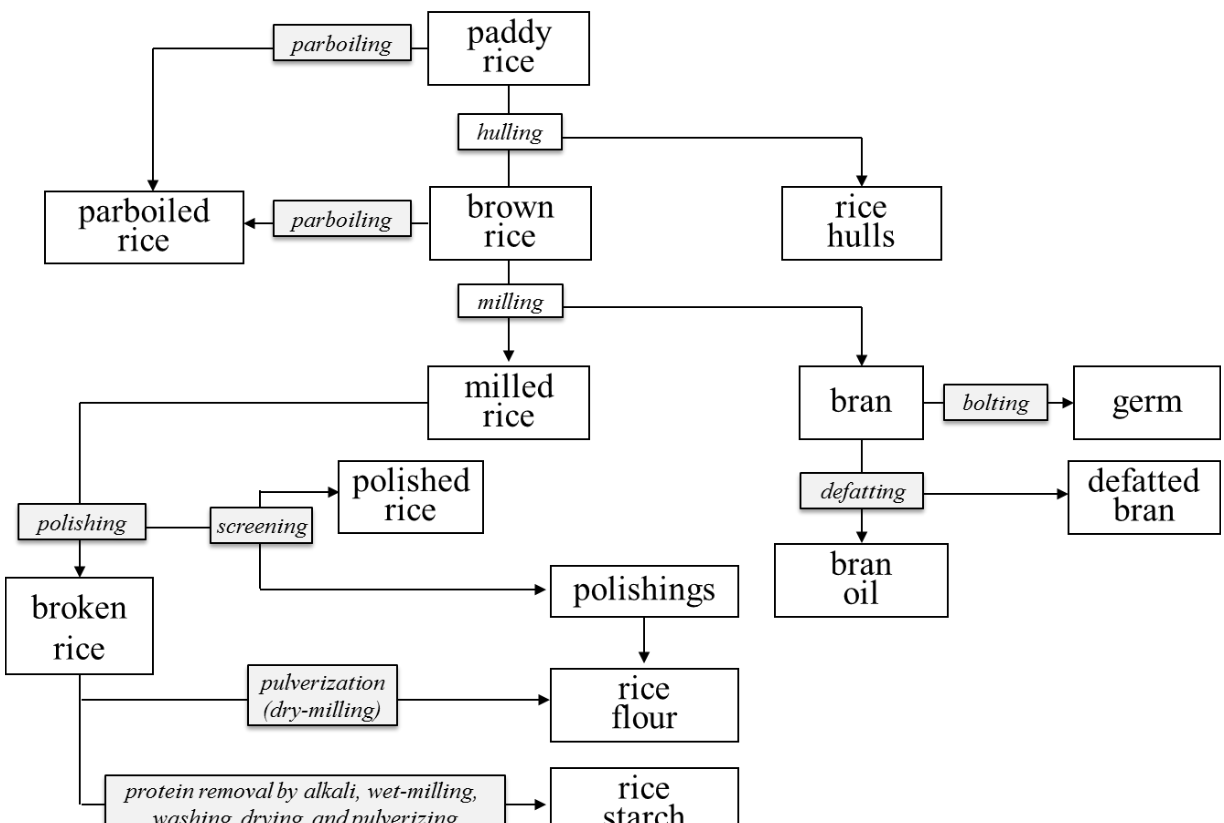
Notes: * 2017 data.
** 2013 data.

Source: IRRI World Rice Statistics (2019), *Paddy Rice Production in 2017*; *Rice Consumption Per Capita in 2013,* http://ricestat.irri.org:8080/wrsv3/entrypoint.htm (accessed on 10 July 2019).

Processing

Paddy rice is processed as shown in Figure 2.3. Parboiled rice is prepared by soaking in water, draining, heating (most often steaming; sometimes under pressure), then drying, followed by hulling and milling. Brown rice is produced from paddy rice by removing the hulls (hulling). Milled rice is derived from brown rice by milling to remove all or most of the bran which primarily consists of a seed coat, aleurone layer and germ. Germ seed is separated through bolting/sieving of the by-products of milling. Milled rice is processed by polishing to remove residual bran on the surface to give a smoother finish and may further be polished to obtain the inner part of rice grain containing less protein for further processing. Most of the rice used for food is milled rice. Rice flour is a pulverised product of the outer part or the whole milled rice. Rice bran oil which is used as cooking oil is made from rice bran by squeezing and, as necessary, successive refining.

Figure 2.3. Rice processing and the resulting products



Source: Satake (1990), *Modern Rice Milling Technology*.

Table 2.5 provides weight ratios for the main rice milling fractions.

Table 2.5. Rice fractions by hulling and milling

Fraction	Ratio (%, on a weight basis)
Hull	16-28 (average 20) of paddy rice
Brown rice	72-84 (average 80) of paddy rice
Milled rice	90 of brown rice
Bran + polishings	10 of brown rice

Source: Adapted from Juliano and Bechtel (1985), "The rice grain and its gross composition".

Uses

Rice is consumed as brown rice, milled rice or parboiled rice after being cooked in the grain form. There are many recipes for cooked brown or milled rice in which rice is boiled, steamed, boiled into porridge or mixed with other grain flours. Boiled or steamed rice can be further baked or fried.

It is estimated that a fifth of the world's consumed rice is parboiled (Bhattacharya, 2004). Use of parboiled rice seems to have increased in recent years due to its numerous advantages: easy hulling, reduced grain breakage during milling, reduced loss of nutrients during washing, maintaining grain integrity after cooking, reduced loss of solids in cooking water, reduced insect infestation and loss of nutrients during storage, high content of bran oil which becomes stable to free fatty acid formation due to inactivation of triacylglycerol lipase by parboiling, and suitability for the production of canned, expanded and flaked rice. A disadvantage to parboiling is the destruction of antioxidants and some B vitamins. Parboiled brown rice as a whole shows lower content of B vitamins but the content depends on its fraction. For example, the content of B vitamins in the parboiled milled rice fraction is higher than in raw milled rice, while that in parboiled bran fraction is lower than in raw rice bran (Padua and Juliano, 1974).

Only a relatively small amount of rice is consumed as prepared rice products worldwide. However, prepared rice products are widely found and consumed in Asia as noodle, cake, cracker, sweets and alcoholic beverages. For example, rice noodles are found in different shapes and given local names in Asian countries such as the People's Republic of China and Thailand. Rice sweets and cakes are also common in Asia. Glutinous rice is used in desserts, rice cakes and ceremonial dishes (Childs, 2004). As for alcoholic beverages, there are rice wines and distilled rice wines in Japan, Korea, and the People's Republic of China. Alcohol from the fermentation of rice flour is partly used for increasing alcohol degree of rice wine.

Poor grade paddy rice and by-products of food processing such as broken rice, hulls, bran, rice flour and hulls/polishings of parboiled rice are used for feed. Defatted bran (cake of rice bran) can be further utilised for feed and as fertiliser.

Appropriate comparators for testing new varieties

This document suggests parameters that rice breeders should measure when developing new modified varieties. The data obtained in the analysis of a new *O. sativa* variety should ideally be compared to those obtained from an appropriate near-isogenic non-modified variety, grown and harvested under the same conditions.[1] The comparison can also be made between values obtained from new varieties and data available in the literature or chemical analytical data generated from other commercial rice varieties.

Components to be analysed include key nutrients and other constituents. Key nutrients are those which have a substantial impact on the overall diet of humans (food) and animals (feed). These may be major constituents (fats, proteins, and structural and non-structural carbohydrates) or minor compounds (vitamins and minerals). Similarly, the levels of other constituents such as anti-nutrients, toxicants and allergens should be considered. Toxicants are those toxicologically significant compounds known to be inherently present in the species, whose toxic potency and levels may impact human and animal health. Standardised analytical methods and appropriate types of material should be used, adequately adapted to the use of each product and by-product. The key components analysed are used as indicators of whether unintended effects of the genetic modification influencing plant metabolism have occurred or not.

Breeding characteristics screened by developers

Phenotype characteristics provide important information related to the suitability of new varieties for commercial distribution. Selecting new varieties is based on data from parental lines. Plant breeders developing new varieties of rice evaluate many parameters at different stages in the developmental process (OECD, 1999). In the early stages of growth, breeders evaluate stand count, seedling vigour, and tillering, and as plants mature, insect-resistance and resistance to disease such as blast disease are evaluated. At near maturity or maturity, heading, maturation, lodging, blanking, shattering, shedding and pre-harvest sprouting (for hybrids) are evaluated. The matured plant is measured for plant height (ground to tip of panicle on the tallest tiller), panicle length, number of panicles, and yield of crop. The harvested grain is measured for yield of grain, moisture, test weight, shape, size, visual quality, dormancy, components content, milling quality and palatability.

Natural variation for agronomic characteristics such as resistance to insect pests and diseases are also considered in the breeding process. More information can be found in the Consensus Document on the Biology of *Oryza sativa* (Rice) (OECD, 1999).

Figure 2.4. Planting in a paddy field

Source: Courtesy of the IRRI, licenced under CC BY-SA.

Conventional breeding of rice, as well as those based on modern biotechnology, can include considerations of nutritive improvements with increased content (biofortification) of elements such as pro-vitamin A, iron, or zinc. In these cases, the amounts of these components are specifically evaluated for those objectives.

Figure 2.5. Growing rice

Source: Courtesy of the IRRI, licenced under CC BY-SA.

Nutrients

Key nutrients in rice products for food use

Key nutrients in rice products for food use are listed in Tables 2.7 and 2.8. Compositional data to compare between indica and japonica varieties are rarely available.

Carbohydrates

Most of the digestible carbohydrates as energy sources are found in the endosperm of rice grain. Milled rice mainly consists of starch with a few other carbohydrates including free sugars and non-starch polysaccharides. The hull is comprised of mostly non-starch polysaccharides such as cellulose and hemicellulose, and it may contain a small amount of starch. The bran and germ are comprised mainly of non-starch polysaccharides such as cellulose and hemicellulose and partly of free sugars as well as a small amount of starch.

Starch

Starch, the principal component of rice, consists of amylose (linear fraction) and amylopectin (branched fraction). Starch in non-glutinous rice is, in general, composed of 10% to 30% amylose and 70% to 90% amylopectin. Starch in glutinous rice contains less than 5% of amylose and consists mostly of amylopectin (Juliano and Villareal, 1993).

Amylose content shows a high positive correlation with the hardness of cooked rice, and it may be used to roughly distinguish between indica and japonica varieties (OECD, 1999).

Amylose content may range depending on the variety: waxy rice (0%-2.0%); very-low-amylose rice (2.1%-10.0%); low-amylose rice (10.1%-17.0%); intermediate-amylose rice (17.1%-22.0%); high-amylose rice (> 22.0%) (Juliano et al., 2012). As amylose content varies depending on the method of analysis: iodine-amylose complex (Juliano et al., 2012), size exclusion (gel permeation) chromatography (Horibata et al., 2004; Nakaura et al., 2011), differential-scanning calorimetry (Mestres et al., 1996), this factor should be considered when comparing the levels among varieties.

Amylose content for a particular variety may show seasonal and regional variations of 1% to 4%, and it does not reach the range observed for varietal differences (Juliano and Villareal, 1993).

Dietary fibre

Although dietary fibre and resistant starch are important nutrients, they are low in cooked rice such as cooked milled rice and milled rice porridge. Dietary fibre is lost by hulling, milling and polishing as shown in Tables 2.7 and 2.8.

Protein

Total protein content in rice is calculated by multiplying total nitrogen content by the rice-specific Kjeldahl conversion factor of 5.95, which is based on the nitrogen content of glutelin, the major protein in rice (Juliano, 1985a). The protein content fluctuates according to the variety grown and can also be affected by growing conditions such as early or late maturing, soil fertility and water stress. The protein content in brown rice ranges from 5% to 17% on a dry matter basis based on the analysis of about 8 000 samples ranging (Juliano, 1968).

Rice proteins are classified based on solubility as albumin (water-soluble), globulin (salt-water-soluble), prolamin (alcohol-soluble) or glutelin (soluble in aqueous alkaline solution) (Hoseney, 1986). The percentage of each protein with respect to the total protein content is shown in Table 2.6. Albumin and globulin have a balanced composition of amino acids. They are found mostly in the outer layer of brown rice, and less in the inner layer of milled rice. Prolamin and glutelin are considesred to be the storage proteins of rice, and the proteins exist in the outer layer and the inside of milled rice. Thus, the protein composition of bran and germ differ greatly from that of milled rice. However, it should be noted that the ratios and the range for each fraction vary widely, depending on the rice variety and the extraction conditions (Shih, 2004).

Table 2.6. Typical proportions of milled rice protein fractions

Protein fraction	Percentage of total protein
Albumin (soluble in water)	2-5
Globulin (soluble in saltwater)	2-10
Prolamin (soluble in alcohol)	20-25
Glutelin (soluble in aqueous alkaline solution)	60-65

Note: Proteins were fractionated by the method of Osborne (Hoseney, 1986).
Source: Ogawa et al (1989), “Mutants for rice storage protein (…)”.

Table 2.7. Proximate, carbohydrate components (% of dry matter) and energy content of paddy rice and brown rice

Nutrient	Paddy rice						Brown rice			
	Juliano and Bechtel (1985)[a]	ILSI-CCDB (2014)[b]		Heuzé, Tran and Hassoun in Feedipedia (2015)		NRC (1982)	Juliano and Bechtel (1985)[a]	USDA (2014)[c]	NARO (2011)[d]	
	range	mean	range	mean	range	mean	range	mean	mean	range
Water (% of fresh weight)	*14*	*16.85*	*9.05-28.35*	*12.0*	*7.6-16.4*	*11.0*	*14*	*11.37*	*13.8*	*12.1-16.4*
Crude protein[e]	6.7-9.0	8.55	7.41-10.00 [f]	8.3	5.9-11.8	8.9 f	8.3-9.7	8.71	7.7	6.5-10.0
Crude fat	1.7-2.7	2.76	2.52-3.47	2.1	1.7-2.6	1.9	1.9-3.3	3.16	3.3	2.8-3.9
Crude ash	3.4-6.0	4.77	3.61-6.54	5.9	3.9-8.6	5.3	1.2-1.7	1.58	1.5	1.2-1.7
Carbohydrates (calculated)[g]		83.91	79.98-85.53					86.55	87.5[h]	85.2-88.9[h]
Digestible carbohydrates	74.0-85.1						84.8-88.2			
Starch	62.1			64.2	61.9-67.2		77.2			
Free sugars	0.6-1.4						0.8-1.5			
Neutral detergent fibre	19.1	18.49	16.15-21.47	21.5	15.0-32.2		4.5			
Acid detergent fibre		15.06	11.79-16.75	13.3	10.8-18.2					
Dietary fibre/ insoluble		18.98	18.84-19.12							
Dietary fibre/ soluble		1.26	-							
Total dietary fibre		19.15	16.73-22.97					3.9		
Crude fibre	8.4-12.1	14.51	10.89-18.13	11.1	8.6-14.8	10.0	0.7-1.2			
Cellulose										
Hemicelluloses										
Pentosans	4.3-6.2						1.4-2.4			
Lignin	4.0			5.4	4.9-5.8					
Energy (kJ/g)	*18.4*			*17.6*	*17.1-22.3*		*17.6-18.7*	*17.3*	*17.4*	*17.2-17.5*

Notes: a. Data from Juliano and Bechtel are presented on a fresh weight basis; values at 14% moisture in the literature were converted to those at percentage of dry matter; b. The data are measured using an indica rice variety; c. Average data for long and medium grains; d. n=138 (data obtained in Japan between 1999 and 2009); the values for each sample were converted to those in dry matter basis by using each moisture content; e. Crude protein = Protein (N x 5.95); f. The conversion factor for ILSI-CCDB and NRC data is not confirmed to be 5.95; g. Carbohydrate (calculated) = 100 – Protein – Crude Fat – Ash – Moisture; h. n=123 (data obtained in Japan between 1999 and 2009); the values for each component reported were converted to dry matter by using moisture content.

Table 2.8. Proximate, carbohydrate components (% of dry matter) and energy content of rice fractions

Nutrient	Milled rice			Bran		Germ	Polishings
	Resources Council STA Japan (2000)	Juliano and Bechtel (1985)[a]	USDA (2014)	Juliano and Bechtel (1985)[a]	USDA (2014)	Juliano and Bechtel (1985)[a]	Juliano and Bechtel (1985)[a]
	mean	range	mean	range	mean	range	range
Water (% of fresh weight)	*15.5*	*14*	*12.31*	*14*	*6.13*	*14*	*14*
Protein (N x 5.95)[b]		7.3-8.3	7.65	13.1-17.3	14.22	16.4-24.0	13.0-14.4
Crude fat		0.3-0.6	0.65	17.4-22.9	22.21	19.3-23.8	11.7-14.4
Crude ash		0.3-0.9	0.64	7.7-11.5	10.63	5.6-10.1	6.0-8.5
Carbohydrates (calculated)[c]			91.07		52.93		
Digestible carbohydrates[d]		89.1-91.2		39.7-60.8		39.8-48.1	59.4-64.0
Starch		90.2		16.0		2.4	48.3-55.3
Free sugars		0.3-0.5		6.4-8.0		9.3-14.0	
Sugar (calculated)[e]			0.14		0.96		
Neutral detergent fibre		0.8-2.7		27.6-33.3		15.2	
Acid detergent fibre							
Dietary fibre/ insoluble	0.5						
Dietary fibre/ soluble	trace						
Total dietary fibre	0.5		2.8		22.4		
Crude fibre		0.2-0.6		8.1-13.3		2.8-4.1	2.7-3.7
Cellulose				6.9-10.5		3.1	
Hemicelluloses		0.1		11.0-19.7		11.3	
Pentosans		0.6-1.6		8.1-9.7		5.7; 7.4	4.2-5.5
Lignin		0.1		33-4.5		0.8-4.7	3.3
Energy (kJ/g)		*17.0-18.1*	*17.3*	*19.4-23.1*	*14.1*		*20.8*

Notes: a. Data from Juliano and Bechtel are presented on a fresh weight basis; values at 14% moisture in the literature were converted to those at percentage of dry matter; b. Crude protein = Protein (N x 5.95); c. Carbohydrate (calculated) = 100 – Protein – Crude Fat – Ash – Moisture ; d. Digestible carbohydrates = Carbohydrates (calculated) – Crude fibre ; e. Sugar (calculated) = Carbohydrates (calculated) – Fibre.

Amino acid composition

The key protein in rice is glutelin (oryzenin) and the most limiting amino acid is lysine. To evaluate the nutritional value of each protein as food, the amino acid score is calculated as follows: 100 x (milligram (mg) of essential amino acid in the protein)/(mg of the essential amino acid in the reference protein ideal for human consumption) (WHO, 1985; 2007). Rice, with an Amino Acid Score (AAS) of 68, offers a more complete and balanced amino acid composition than those of other major cereals such as wheat (medium flour: AAS of 43) and maize (corn grits: AAS of 35), due to its higher contents of lysine and sulphur-containing amino acids (WHO, 1985; 2007). Protein content and amino acid composition vary in paddy and brown rice (Table 2.9).

Table 2.9. Amino acid composition (% of dry matter) of paddy rice and brown rice

Amino acid	Paddy rice			Brown rice		
	Juliano (1985a)[a]	ILSI-CCDB (2014)[b]		Juliano (1985a)[a]	NARO (2011)	
	range	mean	range	range/value(s)	mean	range
Alanine	0.39-0.57	0.44	0.38-0.50	0.54	0.45	0.37-0.59
Arginine	0.61-0.85	0.57	0.53-0.65	0.79-0.98	0.63	0.52-0.88
Aspartic acid	0.61-0.94	0.76	0.68-0.85	0.84-0.88	0.71	0.59-0.96
Cystine	0.10-0.26	0.18	0.15-0.20	0.20-0.22	0.20	0.15-0.28
Glutamic acid	1.31-1.74	1.24	1.10-1.37	1.57-1.64	1.32	1.06-1.88
Glycine	0.35-0.48	0.37	0.34-0.42	0.44-0.45	0.37	0.32-0.48
Histidine	0.14-0.25	0.22	0.20-0.25	0.22-0.24	0.20	0.16-0.27
Isoleucine	0.27-0.43	0.30	0.27-0.34	0.33-0.43	0.29	0.22-0.40
Leucine	0.61-0.78	0.62	0.55-0.71	0.77-0.83	0.62	0.51-0.85
Lysine	0.29-0.42	0.29	0.28-0.32	0.36-0.40	0.30	0.26-0.40
Methionine	0.14-0.31	0.19	0.17-0.21	0.21-0.23	0.22	0.14-0.34
Phenylalanine	0.28-0.52	0.40	0.36-0.44	0.47-0.49	0.40	0.32-055
Proline	0.33-0.54	0.35	0.29-0.42	0.45-0.47	0.34	0.25-0.46
Serine	0.36-0.51	0.40	0.36-0.47	0.45-0.54	0.39	0.30-0.53
Threonine	0.27-0.40	0.30	0.27-0.33	0.36-0.37	0.28	0.23-0.38
Tryptophan	0.11-0.18	0.10	0.09-0.12	0.12-0.14	0.09	0.05-0.13
Tyrosine	0.34-0.48	0.14	0.13-0.18	0.35-0.43	0.32	0.21-0.51
Valine	0.41-0.63	0.43	0.39-0.49	0.47-0.61	0.45	0.37-0.59
Protein (% N x 5.95 dry weight)	*8.5*	*8.55*	*7.41-10.00*	*9.3*	*6.6*	*5.6-8.5*

Notes: a. Data from Juliano presented as g/16.8g N in the literature were converted to percentage of dm based on the protein contents in (%N x 5.95 dry matter).
b. The data are obtained from measurements using an indica rice variety.
c. n=138 (data obtained in Japan between 1999 and 2009).

Lipids

Rice grain lipid is contained mainly in the germ, aleurone layer and sub-aleurone layer. Most of the rice lipids are neutral. They are triglycerides in which glycerol is esterified with three fatty acids, primarily oleic, linoleic, and palmitic acid. Besides triglycerides, free fatty acids, sterol and diglycerides are also found in rice grain. Rice grain also contains lipid-conjugates such as acylsterolglycoside and sterolglycoside, glycolipids such as cerebroside, and phospholipids such as phosphatidylcholine and phosphatidylethanolamine.

Lipids in a starch-lipid complex are not extracted by an organic solvent such as ether, but by water-saturated butanol and others for analyses. The percentage of these lipids contained in non-glutinous brown rice is 0.5%-0.7% and in glutinous brown rice approximately 0.2% respectively. The major lipid components are phospholipids, neutral lipids and glycolipids. Among fatty acids, palmitic and linoleic acids make up a large proportion, and oleic acid makes up a lesser amount (Choudhury and Juliano, 1980a; 1980b).

Fatty acid composition is dependent on the growing season and the varieties adapted to specific eco-geographical conditions. Cultivated rice is eco-geographically classified into four groups of varieties: Indian, Chinese, Japanese and Javanese. The level of palmitic acid is in the order of Indian > Chinese > Japanese > Javanese (Taira, Nakagahra and Nagamine, 1988). In early season crops in Japan, oleic acid content is high due to high temperatures during ripening: similarly, the linoleic acid content is high in late season crops (Kitta et al., 2005). The fatty acid composition of paddy rice and brown rice are given in Table 2.10.

Table 2.10. Fatty acid composition (% of total fatty acids) in paddy rice and brown rice

Fatty acid component	Paddy rice		Brown rice		
	ILSI-CCDB (2014)[a]		Juliano (1985a)	NARO (2011)[b]	
	mean	range	value	mean[3]	range[c]
Myristic (14.0)	0.38	0.32-0.48		0.7	0.5-1.1
Pentadecanoic (15:0)				0.1	0.1-0.3
Palmitic (16.0)	15.44	14.90-16.94	23	21.9	18.2-31.2
Palmitoleic (16:1)	0.41	0.26-0.93		0.2	0.1-0.2
Heptadecanoic (17:0)				0.1	0.1-0.6
Stearic (18:0)	1.88	1.68-2.09		2.0	1.5-2.8
Oleic (18:1)	39.59	37.49-40.49	35	36.9	30.9-42.0
Linoleic (18:2)	37.84	37.51-38.49	38	34.7	26.1-39.0
Linolenic (18:3)	1.15	1.12-1.21		1.2	0.9-1.6
Arachidic (20:0)	0.72	0.66-0.79		0.6	0.4-0.7
Eicosenoic (20:1)	0.56	0.54-0.58		0.5	0.4-0.6
Behenic (22:0)	0.62	0.48-0.82		0.3	0.2-0.6
Docosenoic/Erucic (22:1)	0.20	0.11-0.24		0.1	0.1-0.2
Lignoceric (24:0)	1.18	1.06-1.34		0.6	0.4-0.9
Tetracosenoic (24:1)	0.15	0.12-0.21		0.2	0.1-0.3
Others			4[d]		

Notes:
a. The data are obtained from measurements using an indica rice variety.
b. n = 138 (of only market varieties).
c. Fatty acid profile for fatty acids which are not involved in starch-lipid complexes.
d. Trace to 3% myristic acid; 2%-4% stearic acid; and 1%-2% linolenic acid.

Fatty acid composition appears to be influenced by temperature during the ripening stages. Especially, the amount of polyunsaturated fatty acids decreases with increasing temperature during the ripening stages. However, in some varieties, fatty acid composition does not seem to be influenced by temperature but by genetic factors (Kitta et al., 2005). Rice bran oil contains 4%-8% unsaponifiable matter, rich in *gamma*-oryzanol, tocopherols and tocotrienols.

The content of rice antioxidants, phenolic acids, flavonoids, anthocyanins, proanthocyanidins, tocopherols, tocotrienols and gamma-oryzanol has been reviewed (Goufo and Trindade, 2014).

Minerals

Mineral content is greatly influenced by cultivation conditions including fertilisation and soil conditions. Among the inorganic elements contained in rice, silicon is dominant in paddy rice. The mineral content of paddy rice is detailed in Table 2.11. In brown and milled rice, phosphorus is principal but comparable amounts of potassium, magnesium and silicon are also found (Table 2.12). Phosphorus is primarily found as phytic phosphorus, especially in bran.

Table 2.11. Mineral content in paddy rice

Mineral	Paddy rice					
	Juliano and Bechtel (1985)[a]	ILSI-CCDB (2014)[b]		Heuzé, Tran and Hassoun in Feedipedia (2015)		NRC (1982)
	range	mean	range	mean	range	mean
Macro-minerals (mg/g dry matter)						
Calcium	0.1-0.9	0.32	0.25-0.43	0.6	0.2-1.5	0.7
Magnesium	0.7-1.7			1.0	0.3-1.4	1.5
Phosphorus	2.0-4.5	2.89	2.49-3.35	2.9	1.9-4.7	3.2
Potassium	1.7-4.3			2.8	1.9-3.5	3.6
Silicon	12.6					
Sulphur	0.5-1.9					0.5
Micro-minerals (µg/g dry matter)						
Copper	2-13			3		3.0
Iron	16-70	56.4	36.3-74.2	53		57.0
Manganese	20-109			82	46-117	20.0
Sodium	62-942			300	0-1 000	600
Zinc	2.0-36			14		17.0

Notes: a. Data from Juliano and Bechtel are presented on a fresh weight basis; values at 14% moisture in the literature were converted to those at percentage of dry matter.
b. The data are obtained from measurements using an indica rice variety.

Table 2.12. Mineral content in brown rice and other rice milling fractions

Mineral	Brown rice		Milled rice		Hull	Bran		Germ	Polishings
	Juliano and Bechtel (1985)[a]	USDA (2014)	Juliano and Bechtel (1985)[a]	USDA (2014)	Juliano and Bechtel (1985)[a]	Juliano and Bechtel (1985)[a]	USDA (2014)	Juliano and Bechtel (1985)[a]	Juliano and Bechtel (1985)[a]
	range	mean	range	mean	range	range	mean	range	range
Macro-minerals (mg/g dry matter)									
Calcium	0.1-0.6	0.32	0.1-0.3	0.12	0.7-1.5	0.3-1.4	0.61	0.2-1.2	0.6-0.8
Magnesium	0.2-1.7	1.61	0.2-0.6	0.29	0.3	5.8-15.1	8.32	5-15	7-8
Phosphorus	2.0-5.0	3.36	0.9-1.7	1.11	0.3-0.8	13-29	17.87	12-24	12-26
Potassium	0.7-3.2	2.77	0.8-1.5	0.98	1.7-8.7	12-23	15.82	13-17	8; 13
Silicon	0.7-1.6		0.1-0.5		74-110	3-6		0.5-1.0	1.3; 1.9
Sulphur	0.3-2.2		0.9		0.5	2.0			1.9
Micro-minerals (µg/g dry matter)									
Copper	1-7	3.13	2-3	2.10	35-45	10-40	7.76	10-40	6-30
Iron	2-60	18.5	2-33	18.8	45-110	100-500	197.5	70-209	50-180
Manganese	2-42	42.24	7-20	11.95	116-337	110-267	151.4	106-140	
Sodium	20-395	60	6-100	30	78-960	83-390	50	162-740	trace-160
Zinc	7-33	22.8	7-27	12.9	10-47	50-300	64.3	66-300	20; 70

Note: a. Data from Juliano and Bechtel are presented on a fresh weight basis; values at 14% moisture in the literature were converted to those at percentage of dry matter.

Minerals are unevenly distributed in a brown rice grain. By milling stepwise from the outer layers towards the endosperm of a brown rice grain with an abrasive rice mill, mineral contents in each layer fraction can be measured. Mineral contents in a brown rice grain tend to decrease towards the endosperm. The endosperm contains lesser amounts of minerals than the germ and the outer bran layer fractions (Kubo, 1960; Ohtsubo and Ishitani, 1995).

Vitamins

Rice grain contains water-soluble vitamins such as thiamine (B1), riboflavin (B2), niacin (B3), pyridoxine (B6), cyanocobalamin (B12) and fat-soluble vitamin E, tocopherols. It does not contain significant amounts of other fat-soluble vitamins, like vitamin A, D and K. Vitamins are mainly present in the endosperm and bran layers; thus, milled rice contains fewer vitamins as compared with brown rice (Table 2.13).

Table 2.13. Vitamin content (µg/g dry matter) in paddy rice, brown rice and milling fractions

Vitamin	Paddy rice	Brown rice				Milled rice	Hull	Bran		Germ	Polishings
	Juliano and Bechtel (1985)[a]	Juliano and Bechtel (1985)[a]	NARO (2011)		USDA (2014)[b]	Juliano and Bechtel (1985)[a]	Juliano and Bechtel (1985)[a]	Juliano and Bechtel (1985)[a]	USDA (2015)	Juliano and Bechtel (1985)[a]	Juliano and Bechtel (1985)[a]
	range	range	mean	range	mean	range	range	range	mean	range	range
Retinol (A)	0-0.09	0-0.13	..	..	0	0-trace	0	0-4.2	0	0-1.2	0-1.1
Thiamine (B1)	3.0-3.8	3.4-7.1	5.1	3.6-8.1	4.6	0.2-1.3	1.0-2.4	14-28	28	20-69	4-22
Riboflavin (B2)	0.7-1.3	0.5-1.6	0.5	0.2-0.7	0.8	0.2-0.7	0.6-0.8	2.1-5.0	2.8	2.0-5.0	2.0-2.8
Niacin (B3)	34-65	41-62	79.0	50.4-134.7	53	15-28	19-49	310-580	340	33-97	260-452
Pantothenic acid (B5)	8-14	11-17			16.8	4-8		23-71		13-33	30-65
Pyridoxine (B6)	5-8	6-11	4.4	1.8-6.5	5.7	0.5-1.4		11-33	41	15-17	11-31
Biotin (B7)	0.05-0.09	0.05-0.12				0.01-0.07		0.2-0.6		0.4-0.6	0.1-0.7
Choline, total	880-1 140	1 100				450-1 020		1 070-1 700		1 980; 3 000	1 000-1 450
Folic acid (B9)	0.2-0.5	0.1-0.6			0.2	0.03-0.16		0.5-1.6	0.6	0.9-4.8	1.1-2.1
Cyanocobalamin (B12)	0-0.003	0-0.005			0	0-0.0016		0-0.005		0-0.01	0-0.004
alpha-Tocopherol (E)	10-23	10-29	14.9	8.9-21		trace-3		30-151	49	88	63-100
beta-Tocopherol			0.5	trace-1.4							
gamma-Tocopherol			2.2	trace-4.8							
delta-Tocopherol			0.1	0-0.6							

Notes: .. : missing value or not available.

a. Data from Juliano and Bechtel are presented on a fresh weight basis; values at 14% moisture in the literature were converted to those at percentage of dry matter.

b. Mean of medium- and long-grain brown rice.

Key nutrients in rice products for feed use

According to the OECD guidance document on residues in livestock (OECD, 2013), rice straw is used to prepare feed for cattle and sheep in Australia, Japan and Europe. Whole crop silage is only used in Japan as cattle feed. Rice grain is fed to a wide range of livestock (i.e. cattle, sheep, swine, and poultry) in Australia and the United States. Rice hulls are fed to cattle, sheep, swine and turkeys in Australia. Rice bran and polishings are included in all kind of livestock feed in Australia, Japan, the United States and Europe. Some rice products for feed are common with those for food and the key nutrients for these rice products can be found in the above section “Key nutrients in rice products for food use”.

The whole rice plant is sometimes used for feed, in particular in Japan (Kato, 2008). Table 2.14 provides nutrient values for the whole rice plant at different growth stages. Nutritional composition of the whole rice plant is dependent on its growth stage. Starch content increases as the rice kernel ripens. However, the nutritional value may decrease, if the harvest is delayed until its mature stage. Therefore, rice for feed use is generally harvested at its yellow ripe stage. Crude protein content of whole rice plant at that stage is low (about 7%). The mineral content of rice plant is high; however, the contents of calcium and phosphorus are low as is the case with rice straw. Data on silage (processed whole rice plant) are not listed in the table, since the data are dependent on the process. Silage composition data are available in the following literature: Horiguchi et al. (1992); Nakui et al. (1988); Quinitio, Taji and Kumai (1990); Taji et al. (1991); Taji and Quinitio (1992).

As most of the valuable nutrients are transferred from the leaves and stems to the ripening seeds and stored therein, the straw which consists of the mature stems and leaves contains a relatively small amount of protein, starch, and fat. Rice straw is low in calcium, phosphorus and most vitamins, but high in manganese. The high content of fibre, lignin, and silica are responsible for the low digestibility (Juliano, 1985b).

Table 2.14. Protein, ash, carbohydrate, and fibre content (% of dry matter) of the whole rice plant

Ripening stage

Nutrient	Late vegetative		Early bloom		Milk stage		Dough stage		Yellow ripe		Mature
	NARO (2009)[a]	NARO (2009)[b]	NARO (2009)[a]	NARO (2009)[b]	NARO (2009)[a]	NARO (2009)[b]	NARO (2009)[a]	NARO (2009)[b]	NARO (2009)[a]	Enishi & Shiji-maya (1998)[c]	NARO (2009)[b]
Protein	9.8	14.5	8.4	10.0	8.5	7.4	7.0	6.3	6.5	4.9, 5.0	5.3
NDF	56.2	48.4	58.7	53.0	60.7	52.5	51.0	47.6	48.3	43.4, 56.8	44.1
ADF	30.4	31.2	33.4	33.3	34.5	33.1	31.2	30.7	28.8	26.5, 35.0	28.7
NFE	45.5	41.2	46.50	45.00	47.1	47.9	50.3	51.7	53.5	-	57.3
Ash	15.7	14.5	14.5	13.7	14.0	13.4	13.9	13.2	13.6	-	11.8

Notes: NDF: Neutral Detergent Fibre; ADF: Acid Detergent Fibre; NFE: Nitrogen Free Extract.

a. Data from a rice variety (not specified), which is typically used as forage for animals.
b. Data from a rice variety (not specified), which is typically used as food for humans.
c. Data from high-yielding rice varieties: Hokuriku 147 and Hokuriku 153.

Tables 2.15 and 2.16 show the nutrient content of rice products used as feed from broken rice and for rice straw respectively. For other fractions used as feed components, proximate and other compounds are provided in Tables 2.7 and 2.8 of the section "Key nutrients in rice products for food use" and may provide useful information.

Most animal nutritionists prefer that fibre be measured as neutral detergent fibre (NDF) and acid detergent fibre (ADF) instead of crude fibre. Crude fibre, nitrogen-free extractives (NFE) and ether extract in feed evaluation systems do not sufficiently separate digestible from non-digestible fractions. The determination of NDF and ADF are now widely used for forage and other feed evaluation as they provide useful measurements for nutritionally important parameters, such as structural carbohydrates (Mueller-Harvey, 2004). Both of these measures are used to calculate feed energy values.

Table 2.15. Proximate, fibre, major minerals and amino acid contents (% of dry matter) of rice products used as feed – Broken rice

Component	Broken rice			
	Farrell and Hutton (1990)	NRC (1982)	NRC (1994)	NRC (2012)
		mean	mean	mean
Moisture (% fw)[a]	*12.35*	*11*	*11*	*11*
Dry matter (% fw)[a]		*89*	*89*	*89*
Protein (N x 6.25)[b]	8.1	8.6	9.78	8.88
Crude fat	1.0			
Neutral detergent fibre				9.74
Acid detergent fibre				5.11
Crude fibre	0.3		11.01	
Ash	0.6			
Starch				60.00
Calcium		0.03	0.09	
Phosphorus		0.3	0.09	
Arginine	0.63, 0.75	0.56	0.83	0.58
Glycine		0.38	0.56	
Histidine	0.18, 0.22	0.2	0.29	0.20
Isoleucine	0.34, 0.40	0.37	0.41	0.38
Leucine	0.65, 0.76	0.77	0.83	0.75
Lysine	0.30, 0.36	0.3	0.48	0.34
Methionine	0.21, 0.26	0.14	0.25	0.20
Cystine		0.09	0.24	0.12
Phenylalanine	0.43, 0.50	0.44	0.54	0.44
Serine		0.46	0.49	
Threonine	0.27, 0.32	0.27	0.4	0.29
Tryptophan		0.11	0.11	0.11
Tyrosine	0.29, 0.37	0.46	0.37	0.43
Valine	0.46, 0.85	0.53	0.61	0.55

Notes: For paddy rice, brown rice or other rice fractions used as feed, refer to Tables 2.7 and 2.8 in the Section on key nutrients.
a. % fw: data on fresh weight basis.
b. Animal scientists commonly use a conversion factor of N x 6.25 for crude protein (AOAC, 2002).

Table 2.16. Proximate, fibre, major minerals and amino acid contents (% of dry matter) of rice products used as feed – Rice straw

Component	Rice straw												
	Drake et al. (2002)	Enishi, Shijimaya and Ohta (1995)	Itoh et al. (1975)	Rahal, Singh & Singh (1997)	Wanapat et al. (1996)	Nour (2003)	Juliano (1985b)[a]	ILSI-CCDB (2014)[b]		Jin and Chen (2007)		Heuzé and Tran in Feedipedia (2015)	
								mean	range	mean	range	mean	range
Moisture (% fw)[c]								*55.15*	*41.71-73.69*				
Moisture (% adw)[d]			*9.5*							*6.9*	*4.2 – 9.8*		
Dry matter (% fw)[c]	*90*				*93*	*90.93*						*92.8*	*89.3-96.5*
Protein (N x 6.25)[e]	2.9-7.5	3.0-5.4	4.8	5.4-8.3	4.25	4.62	6.0	5.99	4.02-8.33			4.2	2.4-6.8
Crude fat			1.6	1.3-4.2[f]		1.14[f]		2.46	1.92-3.52			1.4	0.9-2.1
Neutral detergent fibre			73.6	67.9-73.8	78.6			61.97	51.89-70.32			69.1	61.7-78.6
Acid detergent fibre	41.4-56.7	38.3-45.2	44.6	45.3-52.4	47.2			43.27	36.12-55.29			42.4	36.7-52.0
Crude fibre			32.6			35.39						35.1	29.8-41.5
Ash			13.7	12.2-20.8	14.6	20.32		14.25	10.75-18.88	11.8	7.8-15.6	18.1	12.0-24.0
Carbohydrates								77.17	71.04-81.64				
Starch													
Lignin			7.3							10.2	7.2 -12.8	4.8	2.9-7.1
Energy (kJ/g DM)												15.5	15.1-16.8
Calcium	0.21-0.71											0.29	0.17-0.44
Phosphorus	0.07-0.16											0.09	0.05-0.17
Arginine							0.31						
Glycine							0.31						

Component	Rice straw												
	Drake et al. (2002)	Enishi, Shijimaya and Ohta (1995)	Itoh et al. (1975)	Rahal, Singh & Singh (1997)	Wanapat et al. (1996)	Nour (2003)	Juliano (1985b)[a]	ILSI-CCDB (2014)[b]		Jin and Chen (2007)		Heuzé and Tran in Feedipedia (2015)	
								mean	range	mean	range	mean	range
Histidine							0.13						
Isoleucine							0.27						
Leucine							0.45						
Lysine							0.33						
Methionine							0.16						
Cystine							0.11						
Phenylalanine							0.32						
Threonine							0.33						
Tryptophan							0.05						
Tyrosine							0.2						
Valine							0.38						

Notes: For paddy rice, brown rice or other rice fractions used as feed, refer to Tables 2.7 and 2.8 in the Section on key nutrients.

a. n = 2 varieties.
b. The data are obtained from measurements using an indica rice variety.
c. % fw: data on fresh weight basis.
d. % adw: data on air-dried weight basis.
e. Animal scientists commonly use a conversion factor of N x 6.25 for crude protein (AOAC, 2002).
f. Crude fat determined as ether extract.

Other constituents

Anti-nutrients and toxicants

Generally, rice is considered to be a safe source of food. There are a few compounds in rice which are not favourable for human or animal nutrition, but these compounds have not historically been present in rice-based foods at levels that would cause the food to be unsafe. These anti-nutritional factors, most of which are concentrated in the bran, are phytic acid, trypsin inhibitors and hemagglutinin-lectins, oryzacystatin and alpha-amylase/ subtilisin inhibitor. With the exception of phytic acid, the other anti-nutritional factors are proteinaceous in nature and can be subjected to denaturation by heat.

Phytic acid

In most plant materials, large portions of phosphorus are present in the form of phytic acid. Phytic acid is regarded as the primary storage form of phosphorus and inositol in almost all seeds. Phytin is the calcium-magnesium salt of phytic acid. During germination, phytin is hydrolysed by the enzyme phytase, also present in seeds, and serves as a source of inorganic phosphorus and cations for the emerging seedling (Cheryan and Rackis, 1980).

Free phytic acid binds metal ions such as zinc, iron and magnesium in the digestive tract and reduces their availability for absorption, although binding of calcium to phytic acid is pH-dependent (Thompson and Weber, 1981). The phytate-mineral complexes formed are generally insoluble at physiological pH, making the minerals biologically unavailable to mono-gastric animals and humans. Ruminants utilise considerably more phosphorus since rumen microbes produce phytase that breaks down phytate and releases phosphorus. It is common for feed formulators to add phytase to swine and poultry diets to improve the utilisation of phosphorus. Phytic acid may also form complexes with proteins and has been found to inhibit polyphenol oxidase, alpha-amylase, alcohol dehydrogenase, trypsin and other enzymes (Cheryan and Rackis, 1980).

Maga (1982) reported that brown rice contained 0.89% phytic acid whereas the germ had 3.48%, and the pericarp had 3.37% with the endosperm having 0.01%, based on dry weight. Ravindran, Ravindran and Sivalogan (1994) reported phytic acid contents of 0.99 g/100 g dm, 0.60 g/100 g dm, and 3.65 g/100 g dm in brown rice, milled rice and rice bran respectively. Phytic acid contents in brown rice vary between 0.9% to 1.2% dm, whereas those in milled rice are from 0.1% to 0.3% dm (Fretzdorff, 1992). Oberdoerfer et al. (2005) reported phytic acid contents in paddy rice, milled rice and rice bran were determined as 0.83% dm, 0.29% dm, and 5.14% dm respectively.

Trypsin inhibitors

Trypsin inhibitors are proteins known to inhibit biologically active trypsin, interfere with digestion and ultimately absorption of food material, and thus act as anti-nutrients. They are typical anti-nutritional components in soybeans, cereals and potatoes. Proteinase inhibitors are of particular significance in animal nutrition causing growth depression and pancreatic hypertrophy (Liener, 1953).

A trypsin inhibitor was isolated from rice bran and characterised by Tashiro and Maki (1979). These investigators reported a specific activity of 0.011-0.045 units per mg protein in defatted rice bran (Tashiro and Maki, 1979; Maki and Tashiro, 1983). Rice bran trypsin inhibitor (RBTI) is a powerful inhibitor of bovine, swine and rat trypsins, and a partial inhibitor of human trypsin (Tashiro and Maki, 1979).

Trypsin inhibitors are susceptible to heat. No trypsin inhibitor activity was found in paddy rice and milled rice (<1.0 trypsin inhibitor units [TIU]/mg dm). Rice bran samples had an activity of 2.27 TIU/mg dm (Oberdoerfer et al., 2005).

Lectins

Lectins are carbohydrate-binding proteins and may agglutinate cells and precipitate glycoconjugates or polysaccharides (Goldstein et al., 1980). The toxicity of lectins is due to their ability to bind to specific carbohydrate receptor sites on the intestinal mucosal cells and interference with the absorption of nutrients across the intestinal wall (Liener, 1986).

Hemagglutinin activity is confined to the germ or primary axis of the rice grain (Peumans, Stinissen and Carlier, 1983). Whole rice grain and white rice did not show any hemagglutinating activity against red blood cells of rat, rabbit, monkey and human erythrocytes (A, B, and 0) (Ayyagari, Rao and Roy, 1989; Amann, 1998). The rice bran lectin has been found to be associated with agglutination of human A, B and O group receptors with specific binding to 2-acetamido-2-deoxy-D-glucose (Poola, 1989). Rea, Thompson and Jenkins (1985) reported lectin activity of white rice to be below the limit of detection (less than 1.3 HU/mg). Rice bran lectin is heat-labile at temperatures above 80°C (Ory, Bog-Hansen and Mod, 1981; Poola, 1989). Mannose-binding rice lectin is distributed in all parts of the rice plant and it has a potential ability to agglutinate bacterial cells of *Xanthomonas campestris* pv. *oryzae*, the pathogen causing bacterial leaf blight in rice, and also spores and protoplasts of *Magnaporthe grisea*, the rice blast fungus (Hirano et al., 2000). Haemagglutinating activity was found to be below the limit of quantification (<0.1 HU/mg dm) in paddy rice and milled rice (Oberdoerfer et al., 2005).

Oryzacystatin

Oryzacystatin is a proteinaceous (globulin) cysteine proteinase inhibitor (cystatin) from rice grain and is probably the first well-defined cystatin superfamily member of plant origin (Abe et al. al.,; 1987; 1991). Oryzacystatin has been isolated from rice bran. Oryzacystatins I and II are synthesised in rice seeds during maturation. They occur in the cytosol and are decomposed as soon as germination starts (Abe et al. al., 1987; Kondo et al. al. 1990). Oryzacystatin is inactivated by heat above 120°C (FAO, 1993), where retort (pre-cooked) rice is processed. It effectively inhibited cysteine proteinases such as papain, ficin, chymopapain and cathepsin C and had no effect on serine proteinases (trypsin, chymotrypsin, and subtilisin) or carboxyl proteinase (pepsin) (FAO, 1993).

Rice alpha-amylase/subtilisin inhibitor (RASI)

The amino acid sequence of the bifunctional rice alpha-amylase/subtilisin inhibitor (RASI) is known, and it has been cloned and expressed in bacteria (Ohtsubo and Richardson, 1992; Yamagata et al. al., 1998). It is a 21 kDa protein which is expressed only in seed (Yamasaki et al, 2006). The bifunctional RASI inhibits rice alpha-amylase more than barley alpha-amylase (Yamagata et al. al., 1998). These inhibitors have been proposed to be associated with the defensive function of the seed against insect pests and pathogenic microorganisms (Franco et al. al., 2002).

Allergens

Rice is not considered by allergists to be a common allergenic food. However, rice allergy has been reported in Asian countries including Indonesia, Japan, Malaysia and Thailand, as well as some European countries like Denmark, Estonia, Finland, France, Lithuania, Spain Sweden, as well as the Russian Federation (Besler, Tanabe and Urisu, 2001; Kumar et al. al., 2007). Rice allergy is more common in East Asian countries than in Europe and the United States where it is considered rare. The prevalence of IgE-mediated rice allergy is about 10% in atopic subjects in Japan. Rice allergy is more prominent in adults than in children. Symptoms frequently associated with rice allergy are atopic dermatitis, eczema and asthma. Anaphylactic reactions have been reported in severe cases (Besler, Tanabe and Urisu, 2001).

While rice is not considered to be a common allergic food, allergic reactions have been documented and proteins in rice grain have been shown to be IgE-binding proteins. The first demonstration of a rice protein binding to human sera from patients allergic to cereal grain was demonstrated in 1975 (Hoffman, 1975). Allergenicity from the rice protein fractions containing albumin, globulin and glutelin was first reported in Japan in 1979 (Shibasaki et al. al., 1979). A group of rice allergens including 14-16, and 33 kDa proteins of rice seeds have been identified and shown to be IgE-binding proteins (Alvarez et al., 1995; Nakamura and Matsuda, 1996; Tada et al. al., 1996; Trcka et al., 2012; Limas et al. al., 1990; Kumar et al. al., 2007). These rice food allergens, Oryza glyoxalase I (33 kDa) and Oryza trypsin alpha-amylase inhibitors (14-16 kDa), are listed in a database of the Food Allergy Research and Resource Program (FARRP, 2014). In addition, certain proteins with molecular weights of 9, 14, and 31 kDa appear to be rice allergens in children (Jeon et al. al., 2011). However, clinical correlations have not been fully established.

There are two putative rice food allergens, Oryza trypsin alpha-amylase inhibitors (14-16 kDa) and Oryza glyoxalase I (33 kDa), which are listed in a database of the Food Allergy Research and Resource Program (FARRP, 2014).

14-16 kDa proteins

The first reported rice allergens were 14-16 kDa proteins (also called the RAG2 proteins), which were detected using sera from patients allergic to rice (Matsuda et al. al., 1988; Alvarez et al. al., 1995; Tada et al., 1996). The 14-16 kDa protein family was isolated and characterised to be the alpha-amylase/trypsin inhibitor family, constituting multigene families which are immunologically cross-reactive proteins (Alvarez et al. al., 1995). It was confirmed that the 16 kDa rice protein was a relevant rice allergen among atopic patients in Japan (Urisu et al., 1991). The 16 kDa protein has significant amino acid homology to barley trypsin inhibitor and wheat alpha-amylase inhibitor which have been shown to be allergens (Izumi et al., 1992).

33-kDa protein

The 33-kDa allergen was identified to be a novel type of plant glyoxalase I that was expressed in various plant tissues, including maturing seeds, stem, and leaf (Usui et al., 2001) and was initially designated as Glb33.

Suggested constituents to be analysed related to food use

Key rice products for food

Brown, milled, polished and parboiled rice are the major rice products consumed by humans in the form of grain after being cooked. Rice is also consumed as food ingredients which are part of food products. For example, rice flour is used in cereals, baby food, and snacks. The primary nutrients provided by rice are carbohydrates and proteins. Rice bran also provides some vitamins, fat and fibre. Rice oil extracted from bran is valued as high-quality cooking oil.

As compared with the consumption of cooked milled or brown rice, a relatively small amount of rice is consumed as prepared products; a variety of such products is available in the market, in particular in Asia.

More detailed information on the uses of rice and rice products as food is given in above Background section.

Recommendation of key components to be analysed related to food use

Table 2.17 shows suggested nutritional and compositional parameters to be analysed in rice matrices for food use.

Table 2.17. Suggested nutritional and compositional parameters to be analysed in rice matrices for food use

Parameter	Paddy rice or Brown rice
Proximates[1]	x
Total dietary fibre	x
Vitamins[2]	x
Amino acids	x
Fatty acids	x

Notes: 1. Proximates includes moisture, protein, fat, ash and carbohydrate (calculated).
2. B vitamins, namely thiamine (B1), riboflavin (B2), niacin (B3), pantothenic acid (B5) and Pyridoxine (B6), and E vitamin alpha-tocopherol are suggested.

Suggested constituents to be analysed related to feed use

Key rice products for feed

Animals are fed paddy rice and its by-products such as rice straw, rice hulls and rice bran. Whole rice plants can be fed as whole crop silage. Rice and rice products are used as feed in some countries like Japan.

Paddy rice

The use of paddy rice and brown rice is limited as animal feeds because of the cost. Paddy rice is mostly consumed by humans, and fed to livestock only when the quality is poor or off-grade. Because of the hull, paddy rice is higher in crude fibre content and lower in caloric content than brown rice.

Paddy rice can replace other grains in animal feeding. For dairy and beef cattle diets, paddy rice can replace maize at the maximum rates of 40% (hereafter, in weight percentages) and 65% respectively (JSFA, 1979a; 1979b). For poultry and swine, paddy rice can replace maize up to 60-65% (JSFA, 1979a). As rice endosperm is hard and enclosed in hard rice hull, paddy rice should be ground for efficient feed use.

Brown rice is an excellent animal feed, but is usually too expensive for such use. For swine and poultry feeds, brown rice can replace maize at a rate of 40% (JSFA, 1970). Brown rice should be ground before used as animal feed except in the case of poultry. It is also an excellent poultry feed because of its high energy and low fibre content. As paddy rice is lacking carotene, the colour of egg yolks will become paler as rice content of poultry feed increases (JSFA, 1970). Broken rice is commonly used particularly in pet foods in the United States.

Rice provides a number of other by-products that are valuable feedstuffs through harvest and processing: straw, hull, bran, and whole rice plant.

Straw

As rice straw is high in fibre, it can be fed to ruminants as roughage. In the tropical zone of monsoon Asia, rice straw is used as roughage especially in the dry season.

Ruminants cannot subsist only on rice straw because of its low protein content (Table 2.16). Thus, an adequate protein balance should be achieved by supplementing the straw. Rice straw can only partly replace forage because of the low protein content and low digestibility. The straw contains oxalates that chelate calcium and decrease its absorption. Rice is coated with prickly hairs to which cattle need some time to adapt. Rice straw containing less than 50% acid detergent fibre (ADF) could be good forage.

Others

The hull is not a very good feed, as it is very low in protein and high in fibre. The sharp edges of the hull that may irritate the digestive tract of cattle should be broken by sufficiently grinding the hull. Digestibility can be improved by specific processes which remove silica. Monocalcium phosphate is added to the hull, and the mixture is ammoniated under heat and pressure to make an acceptable sheep feed. The hull is commonly used as a carrier for mineral and animal drug premixes.

Rice bran is a good source of protein and vitamins. The quality of rice bran feed is dependent on the hull content. Fresh bran is fairly palatable. However, it often turns rancid during storage unless treated with heat, because of the high oil content and the release of enzymes during processing. Heating and drying at milling can improve storage life (Morimoto et al., 1985).

Rice bran is a good feed component for dairy cows unless the bran amount exceeds 20% of the concentrate feed mixture. In Japan, rice bran has been used as one of the most important feed ingredients for Japanese Black cattle (known as Wagyu in Japanese). Ricebran can be blended up to 20% of swine feed (OECD, 2013). When too much rice bran is fed to juvenile pigs, it may lead to serious scouring. Due to the fatty acid composition in bran, swine and dairy cattle fed with bran in excess may lead both body fat and butter fat to undesirable soft characteristics (Morimoto et al., 1985).

Rice bran can replace wheat bran or wheat middling in poultry feed. The bran contains a high amount of phytate (3% to 5%) which reduces the availability of minerals, and particularly phosphorus (NRC, 2012). Compared with rice bran, defatted rice bran has a long storage life and a high content in crude protein, crude fibre and ash.

Rice polishings also find their way into animal diets because they are an excellent source of nutritionally important vitamins such as thiamine (vitamin B1) and niacin (vitamin B3). Like rice bran, rice polishings easily become rancid during storage and should be fed as fresh as possible. Polishings can be used as a part of the concentrate feed mixture for dairy and beef cattle, and are good feed for swine.

Rice screenings, a mixture of small and broken rice seeds, can be used for feed. However, the nutrient content of screenings is highly variable.

In Japan, whole rice plants can be fed to dairy and beef cattle after *ensilaging*. Its nutritional value is almost equivalent to that of barley whole crop silages (Horiguchi et al., 1992). Rice whole crop silage is low in crude protein and calcium, which should be supplemented (Table 2.14). Rice whole crop silage is palatable for cows (Goto et al., 1991) and dry matter intake by dairy cows ranges from 6.3 to 9.5 kg per day (Ishida et al., 2000). There is only limited compositional information on the whole rice plant.

Recommendation of key components to be analysed related to feed use

The components in the by-products as feed may change during their processing and storage, and the analysis of components must be carried out after storage of the harvested materials under proper conditions.

The suggested nutritional and compositional parameters to be analysed in rice matrices for animal feed use are shown in Table 2.18. In addition to proximate analysis, calcium and phosphorus need to be analysed in rice straw or whole rice plant which is fed to ruminants. Moreover, when using rice grain and its by-products as feed for swine or poultry, amino acids and phytic acid should also be analysed.

Table 2.18. Suggested nutritional and compositional parameters to be analysed in rice matrices for feed use

Parameter	Paddy rice	Straw or Whole plant
Proximates[1]	x	x
Acid detergent fibre		x
Neutral detergent fibre		x
Amino acids	x	

Note: 1. Proximates includes moisture, protein, fat, ash and carbohydrate (calculated).

Note

[1] For additional discussion of appropriate comparators, see the Guideline for the Conduct of Food Safety Assessment of Foods Derived from Recombinant DNA Plants CAC/GL 45/2003 of the Codex Alimentarius Commission (paragraphs 44 and 45).

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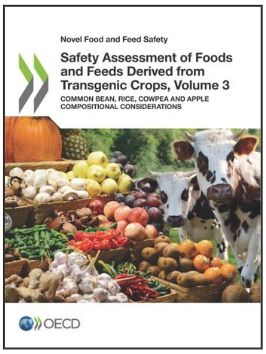

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