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Series on the Safety of Novel Foods and Feeds No. 19

CONSENSUS DOCUMENT ON COMPOSITIONAL CONSIDERATIONS FOR NEW VARIETIES OF GRAIN SORGHUM [Sorghum bicolor (L.) Moench]: KEY FOOD AND FEED NUTRIENTS AND ANTI-NUTRIENTS

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Series on the Safety of Novel Foods and Feeds

No. 19

Consensus Document on Compositional Considerations for New Varieties of GRAIN SORGHUM [*Sorghum bicolor* (L.) Moench]: Key Food and Feed Nutrients and Anti-nutrients

Environment Directorate

ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT

Paris 2010

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or contact:

OECD Environment Directorate,
Environment, Health and Safety Division

2, rue André-Pascal
75775 Paris Cedex 16
France

Fax: (33-1) 44 30 61 80
E-mail: ehscont@oecd.org

FOREWORD

The OECD's Task Force for the Safety of Novel Foods and Feeds decided at its first session, in 1999, to focus its work on the development of science-based ***consensus documents,*** which are mutually acceptable among member countries. These consensus documents contain information for use during the regulatory assessment of a particular food/feed product. In the area of food and feed safety, consensus documents are being published on the nutrients, anti-nutrients or toxicants, information of its use as a food/feed and other relevant information.

This consensus document addresses compositional considerations for new varieties of grain sorghum [*Sorghum bicolor* (L.) Moench] by identifying the key food and feed nutrients and anti-nutrients. A general description of these components is provided. As well, there is background material on the production, processing and uses of grain sorghum and considerations to be taken into account when assessing new varieties of grain sorghum. Constituents to be analysed, related to food use and to feed use, are suggested.

The United States served as the lead country in the preparation for the document, in collaboration with South Africa (co-lead), and the draft has been revised on a number of occasions based on the input from other member countries and stakeholders.

The Task Force endorsed this document, which is published under the responsibility of the Joint Meeting of the Chemicals Committee and the Working Party on Chemicals, Pesticides and Biotechnology of the OECD.

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PREAMBLE

Food and feed products of modern biotechnology are being commercialised and marketed in OECD member countries. The need has been identified for detailed technical work aimed at establishing appropriate approaches to the safety assessment of these products.

At a Workshop held in Aussois, France (OECD, 1997), it was recognised that a consistent approach to the establishment of substantial equivalence might be improved through consensus on the appropriate components (*e.g.*, key nutrients, key toxicants and anti-nutritional compounds) on a crop-by-crop basis, which should be considered in the comparison. It is recognised that the components may differ from crop to crop. The Task Force therefore decided to develop consensus documents on phenotypic characteristics and compositional data. These data are used to identify similarities and differences following a comparative approach as part of a food and feed safety assessment. They should be useful to the development of guidelines, both national and international and to encourage information sharing among OECD member countries.

These documents are a compilation of current information that is important in food and feed safety assessment. They provide a technical tool for regulatory officials as a general guide and reference source, and also for industry and other interested parties and will complement those of the Working Group on Harmonisation of Regulatory Oversight in Biotechnology. They are mutually acceptable to, but not legally binding on, member countries. They are not intended to be a comprehensive description of all issues considered to be necessary for a safety assessment, but a base set for an individual product that supports the comparative approach. In assessing an individual product, additional components may be required depending on the specific case in question.

In order to ensure that scientific and technical developments are taken into account, member countries have agreed that these consensus documents will be reviewed periodically and updated as necessary. Users of these documents are invited to provide the OECD with new scientific and technical information, and to make proposals for additional areas to be considered.

A short, pre-addressed questionnaire is included at the end of this document. The information requested should be sent to the OECD at one of the addresses shown.

THE ROLE OF COMPARATIVE APPROACH AS PART OF A SAFETY ASSESSMENT

In 1990, a joint consultation of the Food and Agriculture Organisation of the United Nations (FAO) and the World Health Organisation (WHO) established that the comparison of a final product with one having an acceptable standard of safety provides an important element of safety assessment (WHO, 1991).

In 1993 the Organisation for Economic Co-operation and Development (OECD) further elaborated this concept and advocated the approach to safety assessment based on substantial equivalence as being the most practical approach to addressing the safety of foods and food components derived through modern biotechnology (as well as other methods of modifying a host genome including tissue culture methods and chemical or radiation induced mutation). In 2000 the Task Force concluded in its report to the G8 that the concept of substantial equivalence will need to be kept under review (OECD, 2000).

The Joint FAO/WHO Expert Consultation on Foods Derived from Biotechnology in 2000 concluded that the safety assessment of genetically modified foods requires an integrated and stepwise, case-by-case approach, which can be aided by a structured series of questions. A comparative approach focusing on the determination of similarities and differences between the genetically modified food and its conventional counterpart aids in the identification of potential safety and nutritional issues and is considered the most appropriate strategy for the safety and nutritional assessment of genetically modified foods. The concept of substantial equivalence was developed as a practical approach to the safety assessment of genetically modified foods. It should be seen as a key step in the safety assessment process although it is not a safety assessment in itself; it does not characterise hazard, rather it is used to structure the safety assessment of a genetically modified food relative to a conventional counterpart. The Consultation concluded that the application of the concept of substantial equivalence contributes to a robust safety assessment framework.

A previous Joint FAO/WHO Expert Consultation on Biotechnology and Food Safety (1996) elaborated on compositional comparison as an important element in the determination of substantial equivalence. A comparison of critical components can be carried out at the level of the food source (*i.e.* species) or the specific food product. Critical components are determined by identifying key nutrients, key toxicants and anti-nutrients for the food source in question. The comparison of key nutrients should be between the modified variety and non-modified comparators with an appropriate history of safe use. The data for the non-modified comparator can be the natural ranges published in the literature for commercial varieties or those measured levels in parental or other edible varieties of the species (FAO, 1996). The comparator used to detect unintended effects should ideally be the near isogenic parental line grown under identical conditions. While the comparative approach is useful as part of the safety assessment of foods derived from plants developed using recombinant DNA technology, the approach could, in general, be applied to foods derived from new plant varieties that have been bred by other techniques.

SECTION I – BACKGROUND

A. Production of sorghum varieties for food and feed

1. Sorghum includes a wide variety of related plant species used for a variety of purposes. The major species of grain sorghum is *Sorghum bicolor* (L.) Moench, an annual cereal crop of African origin (de Alencar Figueiredo *et al*., 2008). Numerous varieties, including hybrid ones, have been developed by companies and institutions to serve different end-uses (Kriegshauser e*t al.*, 2006; Salinas *et al.*, 2006). Grain varieties of sorghum may be characterized depending on their starch content, structure, and functional properties for cooking (Sang *et al.*, 2008). Some cultivars of *Sorghum bicolor* (L.) Moench are referred to as "sweet sorghums" due to the high sucrose content in their stalks (Ali *et al*., 2008). Broom sorghum (broomcorn, *Sorghum vulgare*) is also grown in some regions of the world; however, the taxonomic designation of *S. vulgare* is now considered to be a subspecies of *S. bicolor* in the main world-wide reference databases (ITIS and GRIN websites, 2009). Sudangrass [*Sorghum sudanense* (Piper) Stapf], classified as a nothosubspecies of *S. bicolor* in the GRIN database, is used as a forage source for livestock in many countries and may be crossed with *S. bicolor* to increase yield. Johnsongrass [*Sorghum halepense* (L.) Pers], a perennial crop, is closely related to Sudangrass but is regarded as a noxious weed in many countries.

2. Sorghum has many other common names including great millet, guinea corn, aura, mtama, jowar, cholam, kaoliang, milo, and milo-maize (FAO, 1995). Sorghum grain consists of three distinct anatomical parts: the outer layer, or pericarp; the storage tissue endosperm; and the germ or embryo. The relative proportions of these parts within the grain depend on the cultivar and environmental conditions. The outermost layer of the pericarp, the epicarp, is usually covered with a thin layer of wax, and two or three cell layers of pigmented cells. Below the epicarp lies the mesocarp, which in sorghum, unlike other cereals, contains starch granules. Most of the starch and protein (including enzymes) is stored in the endosperm of sorghum grain, whereas the germ contains most of the oil and minerals, to support initial growth of the embryonic plant (Serna-Saldivar and Rooney, 1995; Waniska and Rooney, 2000).

3. Approximately 75% of the weight of *S. bicolor* grain is starch, comprised of amylose and amylopectin arranged radially in spherical granules in a pseudo crystalline matrix (having both crystalline and amorphous regions). These granules are insoluble in cold water, and relatively inaccessible to hydrolysis by amylase. Sorghum starch has properties and uses similar to maize starch and the procedures for milling sorghum are similar to that for milling maize. Pigmented sorghum pericarp will sometimes yield starch with a pinkish colour, which can be bleached with $NaClO_2$, or rinsed with NaOH or methanol during wet milling to produce a more acceptable colour (Waniska and Rooney, 2000).

4. Sorghum is considered the fifth most important cereal crop in the world behind wheat, rice, maize, and barley (CGIAR website, 2009). Sorghum is grown on approximately 44 million hectares in 99 countries (ICRISAT, 2009). An estimation of the world-wide tonnage produced in 2007-2008 is shown in Table 1.

Table 1. World Sorghum Production 2007-2008

Country	**Production** (tonnes x 1000)	**% of Total**
United States	12,827	20
Nigeria	10,000	16
India	7,780	12
Mexico	6,100	10
Sudan	4,500	7
Ethiopia	3,230	5
Argentina	2,900	5
Australia	2,691	4
China	1,900	3
Burkina Faso	1,800	3
Brazil	1,700	3
Other countries	*6,880*	*12*
Total	**62,308**	100

Source: U.S. Grain Council (2008)

B. Uses

5. According to the U.S. National Sorghum Producers Association (2006), approximately 50% of the world production of sorghum grain is used as human food, while FAO estimates that 95% of its total food use occurs in Africa and Asia (FAO, 1995). Sorghum grain is a staple diet in Africa, the Middle East, Asia and Central America where its processed grain may be consumed in many forms including porridge, steam-cooked product, tortillas, baked goods, or as a beverage (CGIAR, 2009). Sorghum represents a large portion of the total calorie intake in many African countries (FAO, 1995). China and India account for almost all of the food use of sorghum in Asia. Sorghum is genetically more closely related to maize than it is to wheat, rye or barley, and as such is considered a safe food for patients with celiac disease (Ciacci *et al.*, 2007; U.S. Grains Council, 2008). Several million tonnes of sorghum is used across Africa for traditional beer brewing, and in west, east and central Africa for lager/stout production. Research from Mexico suggests that waxy sorghum (a mutant variety that is nearly 100% amylopectin) may be advantageous for brewing; however, normal sorghum (approximately 75% amylopectin and 25% amylose) is more commonly used for beer production (Del Pozo-Insfran *et al.* 2004; Figueroa *et al.* 1995).

6. In other parts of the world, sorghum grain is used mainly as an animal feed. Such use is concentrated in Mexico, many South American countries, the United States, Japan, and the CIS States. The stover of sorghum also is used as fodder for animals. Brown midrib (BMR) varieties of *Sorghum bicolor* have been developed for use as forage sources for livestock because of their reduced lignin content and higher digestibility of the stover (Aydin *et al.*, 1999; Oliver *et al.*, 2004). Broom sorghum (broomcorn, *S. vulgare*) is also used as a source of animal feed in some regions, although it is less digestible than *S. bicolor* (Nikkhah *et al.* 2004). Sudangrass and sudangrass hybrids may be used as pasture, hay, green-chop or silage for livestock. According to FAO (1995), the use of sorghum for feed has been the driving force behind increasing its global production and trade.

7. Sweet sorghums are used for the production of syrup or molasses, and are being considered as potential sources for fuel ethanol (Gibbons *et al.*, 1986; ICRISAT, 2009). Production of ethanol from sorghum grain or sweet sorghum biomass (stalks) has gained increasing interest in recent years (Ali *et al.*, 2008; Gibbons *et al.*, 1986; Wang *et al.*, 2008; Zhao *et al.*, 2008). To produce ethanol from sorghum grain, the whole grain is ground, gelatinized, and converted to fermentable carbohydrates using enzymes. The by-

product, distillers' grains, contains approximately 30% protein, and is commonly used as feed for livestock in either wet or dry form (Al-Suwaiegh *et al.*, 2002; Lodge *et al.*, 1997; Rooney and Waniska, 2000).

C. Processing

8. Sorghum grain and biomass processing depends on the intended final product. Dry milling of grain is used for production of ethanol, preparation of flour for baking or porridge, or for use as animal feed. Malting is used for production of beverages, porridges, or baked goods. Sorghum stalks and leaves may be crushed to extract juice, or fed green or dried to livestock. Whole sorghum grain used for feeding non-ruminant livestock is processed mainly by hammer milling. The ground meal may be pelleted for use in poultry and swine feeds. Steam flaking is widely used on cattle feedlots to improve palatability and rumen fermentation (Rooney and Waniska 2000, Zinn *et al.*, 2008). The process for elaborating diverse types of animal feed from sorghum is sketched in Figure 1.

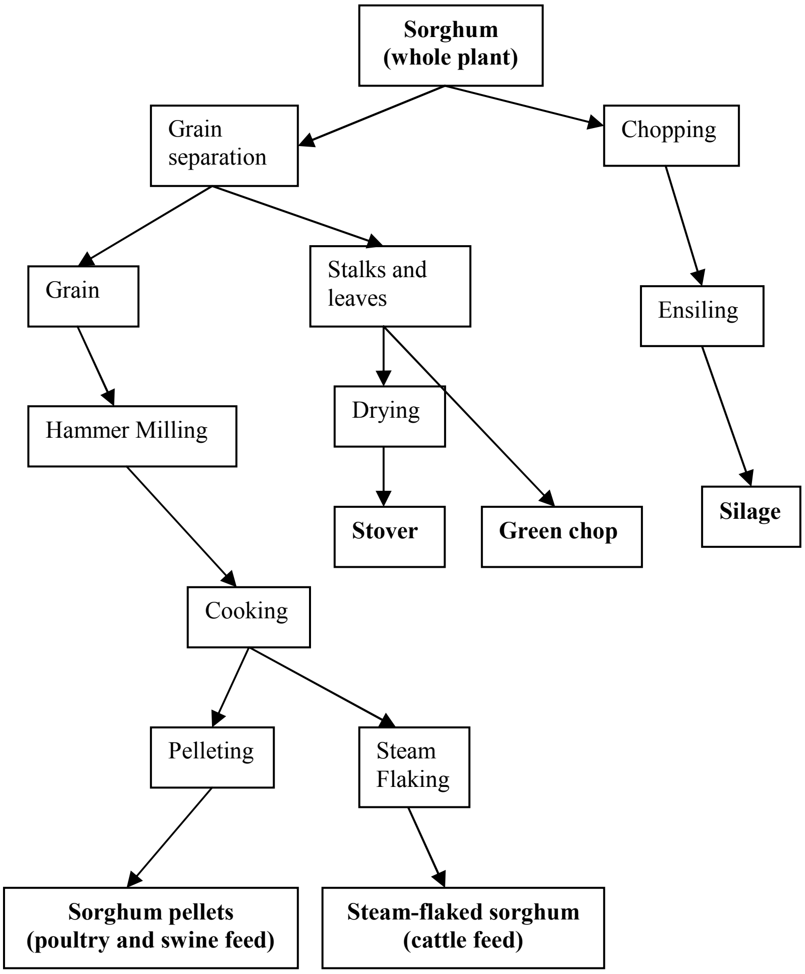

Figure 1. Processing sorghum for animal feed

Source: Rooney and Waniska, 2000

9. There are various methods included in the broad topic of "dry milling" that includes cracking, decortication (dehulling, degermination), hammer milling, disc milling, and roller milling, and may involve more than one of these methods depending on the type of sorghum and the desired end-products. Roller milling works best for sorghums with soft, floury endosperm that is easily crushed and removed from the pericarp. For roller milling, tempering the grain to 15-16% moisture just before milling improves the separation of bran from flour. Dehulling (degermination) produces highly refined fractions of flour, bran, germ, meal, and grits. The milling properties of sorghum are affected by both genetics and environmental conditions (Rooney and Waniska, 2000). The process steps for sorghum grain dry milling are schematized in Figure 2.

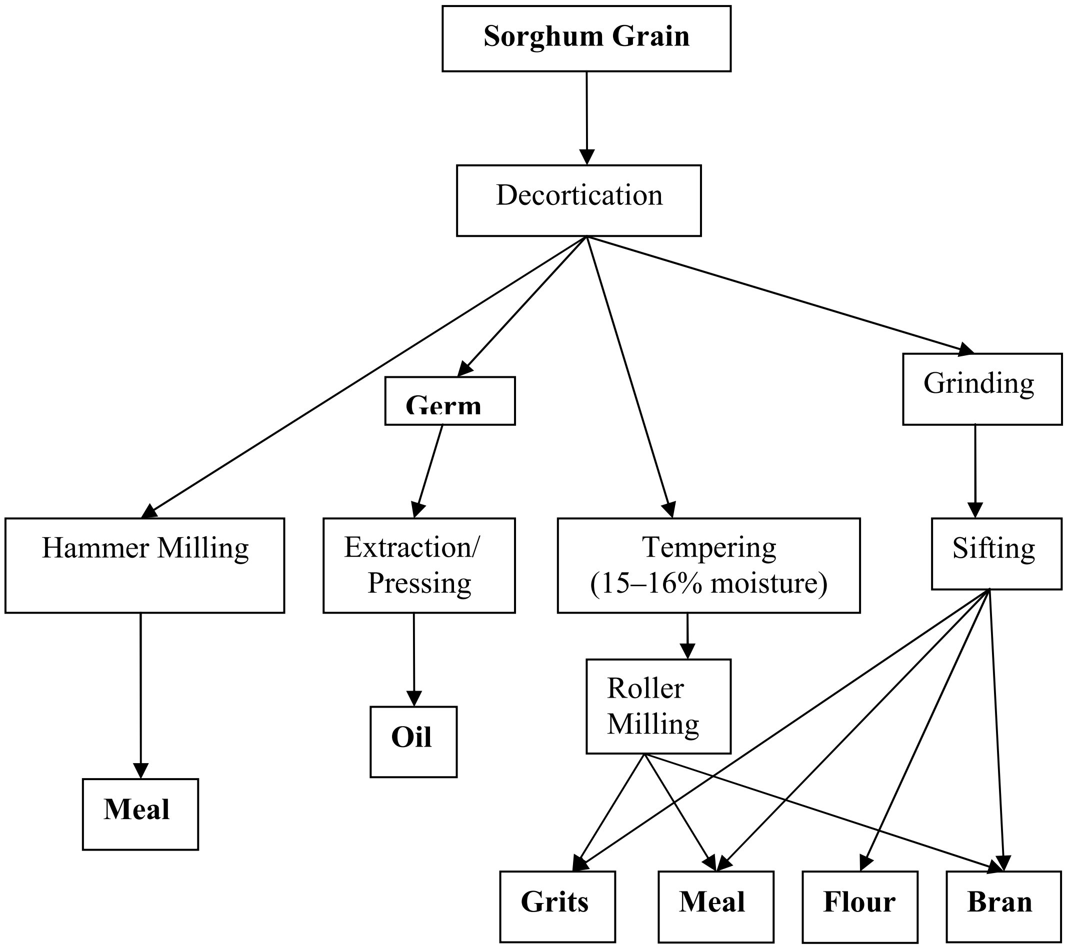

Figure 2. Dry milling sorghum grain

Adapted from: Rooney and Waniska, 2000

10. Sorghum syrup, molasses and sugar are produced from juice extracted from sweet sorghum stalks which are high in sucrose. A roller-type mill is used to extract the juice from the stalks shortly after harvest. The juice is then clarified, typically by heating, and solids are concentrated by evaporating water from the juice to produce syrup. Fermentable carbohydrates in sweet sorghum stalks comprise approximately 80% soluble sugars and 20% starch. To optimize production of ethanol from sweet sorghum biomass requires both liquefying and saccharifying enzymes (Rooney and Waniska, 2000). Figure 3 sketches the sweet sorghum processing.

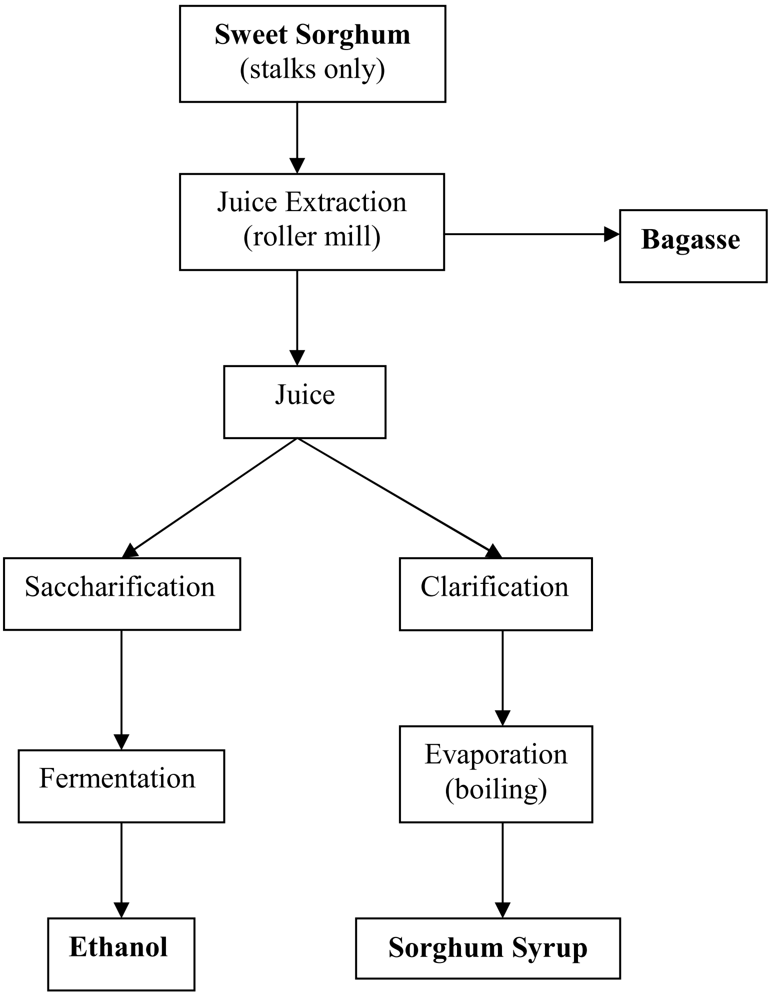

Figure 3. Processing sweet sorghum

Adapted from: Rooney and Waniska 2000

11. Wet milling sorghum to extract starch is not common, but may still be done in some countries to meet demands for starch, particularly if maize is in short supply. Separating starch and gluten is more difficult with sorghum than maize, because of its fragile pericarp (Rooney and Waniska, 2000; Taylor *et al.*, 2006). The process of wet milling of sorghum grain is outlined in Figure 4.

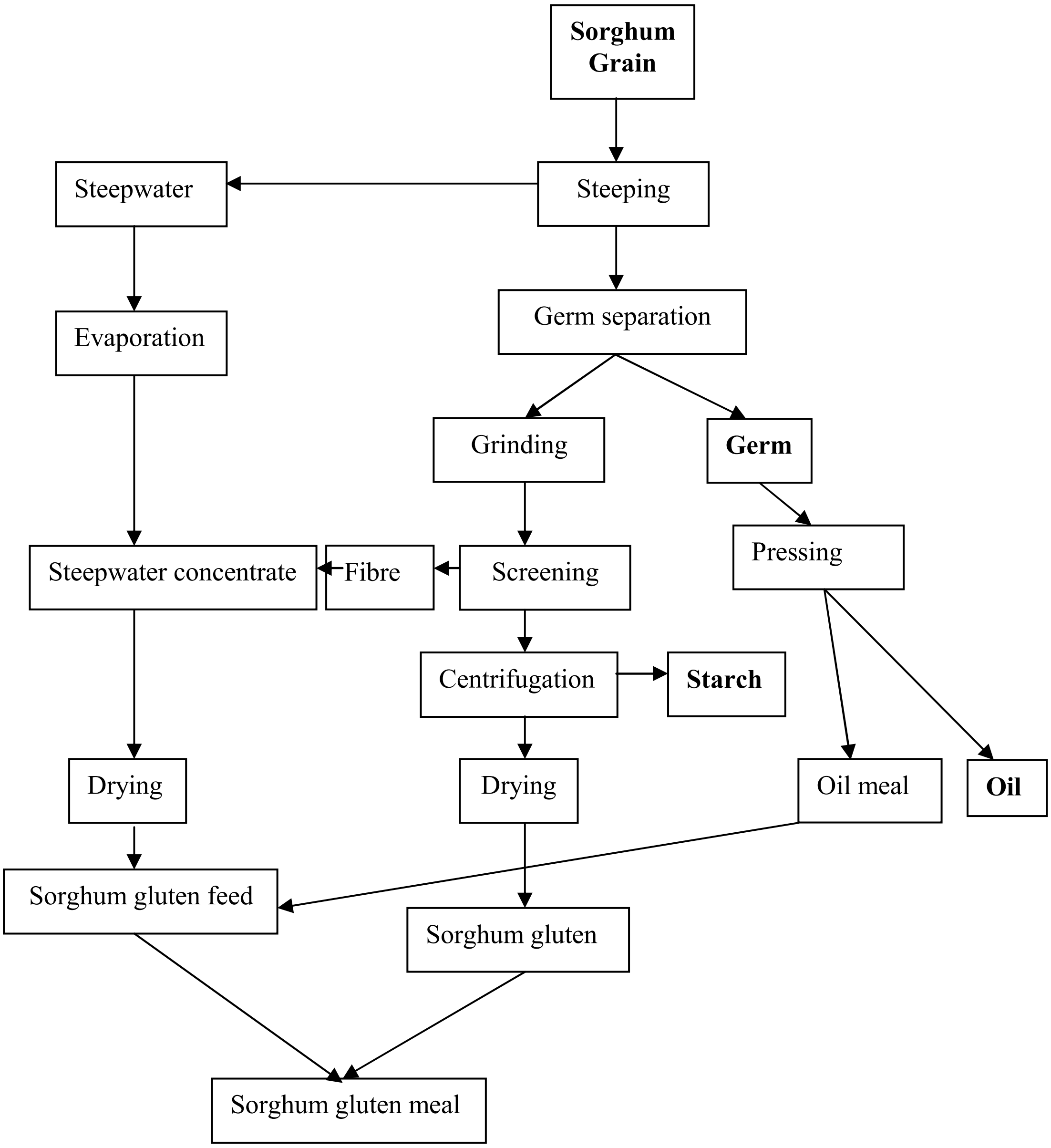

Figure 4. Wet milling of sorghum grain

Adapted from FAO-AFRIS (1993) and Kent and Evers (1994)

12. For production of traditional African sorghum beer, the whole grain is generally malted by steeping, allowing the grain to germinate, and drying. The resulting malt is then ground, mixed with water, mashed (saccharified), filtered, boiled and inoculated with yeast and allowed to ferment to produce a cloudy beer. Alternatively, ground malt is mixed with water, allowed to sour, then boiled with an adjunct (maize or sorghum grits), cooled, and saccharified with additional sorghum malt before inoculating with yeast to produce an opaque beer (Rooney and Waniska, 2000). Figure 5 summarises the whole process.

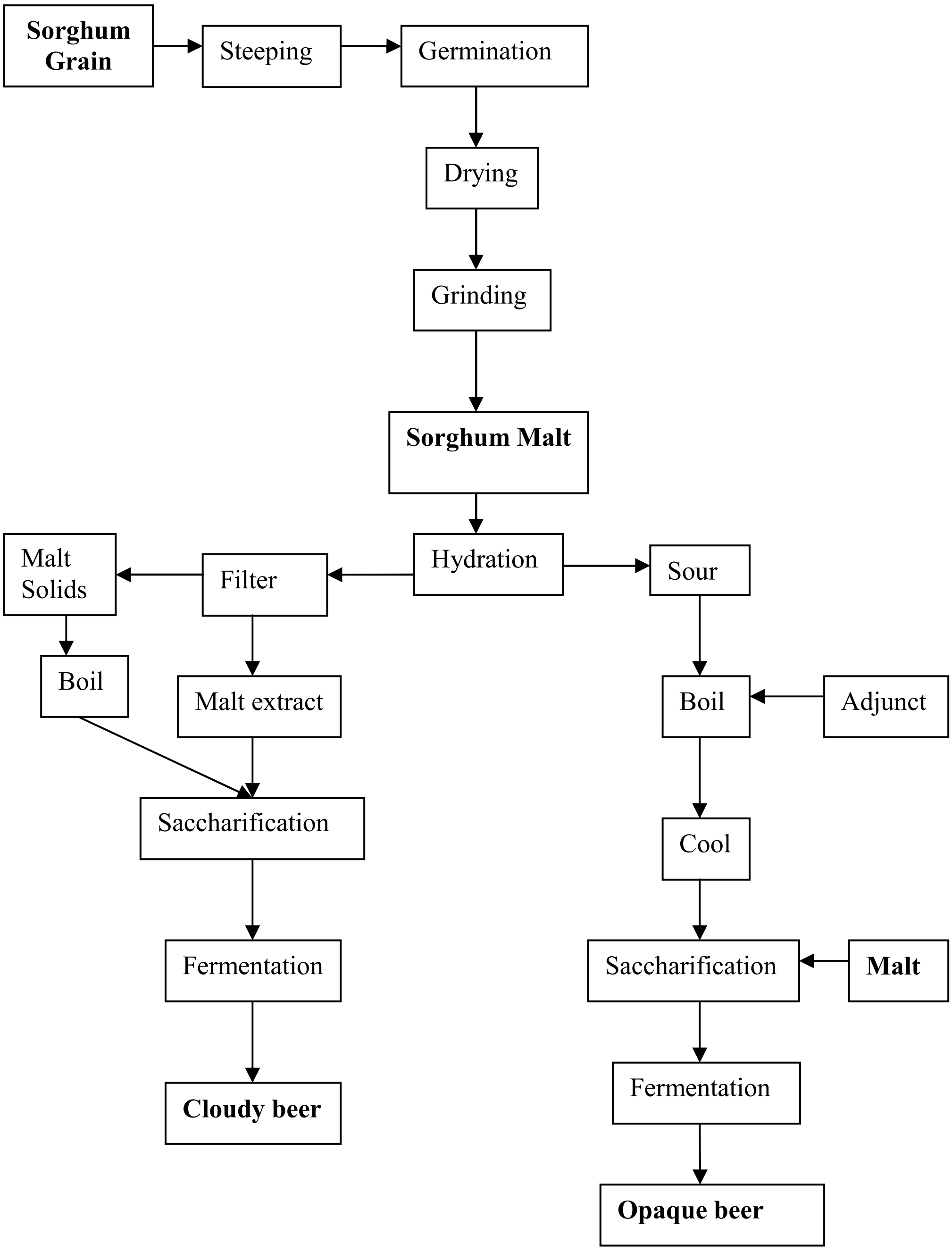

Figure 5. Traditional African sorghum beer production

Adapted from: Rooney and Waniska, 2000

D. Appropriate comparators for testing new varieties

13. This document suggests parameters that sorghum breeders should measure when developing new modified varieties. The data obtained in the analysis of a new sorghum 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 sorghum varieties.

14. Components to be analysed include key nutrients, toxicants and allergens. Key nutrients are those which have a substantial impact in 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 known anti-nutrients and allergens should be considered. Key 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. Standardized 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 has occurred or not.

E. Breeding characteristics screened by developers

15. In the early stages of growth, breeders evaluate germination percentage, emergence, seedling vigour (measured as leaf area, number, length and width assessed at 15-20 days post emergence), and cold tolerance. As the plant matures it is evaluated for plant height, standability, stalk diameter, half-blooming (Liang and Walter, 1968; Rattunde, 1998), drought-tolerance, and pest- and disease-resistance (Krausz *et al*., 1994; Teetes and Pendelton, 1999; Partridge, 2008). The harvested sorghum is evaluated for yield, head type, head weight, kernel number, kernel weight, grain colour, grain size, and threshability (Liang and Walter, 1968; Rattunde 1998). For forage and dual purpose sorghum varieties, days to flower, physiological maturity, plant height, lodging score, stover yield, and biomass yield may also be evaluated (Rattunde 1998).

16. End-use criteria that are evaluated include tannin concentration, endosperm texture and malting quality. These criteria will vary depending on the intended market for the final product. Methods for testing these qualities may be found at the International Association for Cereal Science Technology (ICC website).

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[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).

SECTION II – NUTRIENTS

A. Sorghum grain

17. Grain size, type of pericarp and seed-coat vary among sorghum varieties and affect their nutritional content. Larger grain varieties are associated with higher starch content, while smaller grains often have a proportionally larger germ, and a higher content of oil. Smaller grains typically have a higher seed coat to seed content ratio, and thus have a higher proportion of structural carbohydrate (fibre). Sorghum seeds are small and must be cracked or ground to make the nutrients available. The nutrient composition of sorghum grain is presented in Tables 2 to 6.

Table 2. Proximate analysis of *S. bicolor* grain (dry matter basis)

Measurement	USDA 2009	Ensminger 1990	NRC[1]	Kriegshauser 2006	Preston 2010	Ragaee 2006	FAO[2]	*Range of mean values*
Moisture, %	9.2	10.0	10.0–12.5		11.0		9.3–12.3	*9.2–12.5*
% DM								
Crude Protein[3]	12.4	12.8	10.1–12.6	12.1–14.1	11.0	12.1	10.8–15.6	*10.1–15.6*
Total fat[4]	3.6	2.9	3.0–3.3	3.1–3.8	3.1	3.32	0.8–4.3	*0.8–4.3*
Ash	1.7	1.9	1.9–2.0	1.5–1.6	2.0	1.87	1.5–3.3	*1.5–3.3*
Nitrogen-free extract (NFE) [5]	82.7			70.8–73.3			74.6–84.9	*70.8–84.9*
Crude Fibre	6.9	2.8	2.6–3.0	2.1–2.7	3.0		1.7–2.1	*1.7–6.9*
NDF[6]		18.0	10.9–23.0		15.0			*10.9–23.0*
ADF[7]		9.0	5.0–9.3		6.0			*5.0–9.0*

[1] NRC- Nutrient Requirements of Poultry, 1994; of Swine, 1998; of Beef Cattle, 2000; and of Dairy Cattle, 2001

[2] FAO-AFRIS (1993)

[3] Crude protein = Nitrogen x 6.25

[4] Total fat as measured by ether extract

[5] NFE = 100 - (ash + ether extract + crude protein + crude fibre)

[6] Neutral detergent fibre

[7] Acid detergent fibre

Table 3. Mineral concentrations in *S. bicolor* grain (dry matter basis)

Minerals	**Units**	**Preston 2010**	**Ragaee 2006**	**USDA 2009**	**Ensminger 1990**	**NRC[1]**	***Range of mean values***
Ca	%	0.04	0.03	0.03	0.06	0.03–0.07	*0.03–0.07*
Na	%		0.005	0.01	0.03	0.01	*0.005–0.03*
K	%	0.40	0.24	0.39	0.38	0.38–0.47	*0.24–0.47*
P	%	0.32	0.35	0.32	0.35	0.32–0.36	*0.32–0.36*
Mg	%		0.19		0.16	0.14–0.17	*0.14–0.19*
Cl	%	0.10			0.09	0.06–0.10	*0.06–0.10*
S	%	0.14			0.17	0.09–0.14	*0.09–0.17*
Fe	mg/kg		10.6	48.8	70.0	48.7–89.0	*10.6–89.0*
Co	mg/kg				0.31		*0.31*
Cu	mg/kg		0.2		10.8	4.7–11.5	*0.2–11.5*
Mn	mg/kg				10.9	16.9–21.0	*10.9–21.0*
Se	mg/kg					0.23–0.46	*0.23–0.46*
Zn	mg/kg	18.0			47.1	16.9–25	*16.9–47.1*
Mo	mg/kg					1.0	*1.0*
Cr	mg/kg		0.8				*0.8*

[1] NRC - Nutrient Requirements of Poultry, 1994; of Swine, 1998; of Beef Cattle, 2000; and of Dairy Cattle, 2001

Table 4. Vitamin concentrations in *S. bicolor* grain (dry matter basis)

Vitamins	**Units**	**USDA 2009**	**Ensminger 1990**	**NRC[1]**	***Range of mean values***
A[2]	IU	0.0	2.2	1.0	*0.0–2.2*
D	IU			29.0	*29.0*
E	IU			5.6–12.0	*5.6–12.0*
Thiamin	mg/kg	2.6	5.0	3.4–3.7	*2.6–5.0*
Riboflavin	mg/kg	1.6	1.4	1.5	*1.4–1.6*
Niacin	mg/kg	32.2	52.0	39.0–47.1	*32.2–52.0*
Biotin	mg/kg		0.29	0.29–0.42	*0.29–0.42*
Choline	mg/kg		762	737.0–767.8	*737.0–767.8*
Folacin	mg/kg		0.24	0.19–0.23	*0.19–0.24*
Pantothenic acid	mg/kg		11.3	12.5–14.3	*11.3–14.3*
Pyridoxine	mg/kg		6.0	5.0–6.0	*5.0–6.0*

[1] NRC (1982) United States-Canadian Tables of Feed Composition; NRC- Nutrient Requirements of Poultry, 1994; of Swine, 1998; of Beef Cattle, 2000; and of Dairy Cattle, 2001

[2] Measured as β-carotene

Table 5. Amino acid composition of *S. bicolor* grain (% dry matter basis)

Amino Acid	USDA 2009	NRC[1]	Kriegshauser 2006	FAO[2]	*Range of mean values*
Methionine	0.19	0.15–0.21		0.04–0.06	*0.04–0.21*
Cystine	0.14	0.12–0.22		0.12–0.14	*0.12–0.22*
Lysine	0.25	0.24–0.91	0.25–0.26	0.23–0.29	*0.23–0.91*
Tryptophan	0.14	0.1–0.9	0.09–0.10		*0.09–0.9*
Threonine	0.38	0.33–0.57	0.36–0.4	0.41–0.53	*0.33–0.57*
Isoleucine	0.48	0.4–0.7	0.43–0.49	0.41–0.53	*0.4–0.7*
Histidine	0.27	0.25–0.34	0.28–0.31	0.27–0.35	*0.25–0.35*
Valine	0.62	0.5–0.7	0.57–0.65	0.51–0.65	*0.5–0.7*
Leucine	1.64	1.1–1.6	1.47–1.75	1.5–1.9	*1.1–1.9*
Arginine	0.39	0.4–1.8	0.43–0.47	0.38–0.49	*0.36–1.8*
Phenylalanine	0.60	0.54–0.7		0.59–0.75	*0.54–0.75*
Glycine	0.38	0.35–0.36			*0.35–0.38*
Alanine	1.14				*1.14*
Aspartic acid	0.82				*0.82*
Glutamic acid	2.69				*2.69*
Proline	0.94				*0.94*
Serine	0.51	0.46–0.55			*0.46–0.55*
Tyrosine	0.35	0.19–0.46		0.45–0.57	*0.19–0.57*

[1] Range of values based on NRC (1982) United States-Canadian Tables of Feed Composition; NRC -Nutrient Requirements of Poultry, 1994; of Swine, 1998; of Beef Cattle, 2000; and of Dairy Cattle, 2001

[2] FAO-AFRIS (1993)

Table 6. Fatty acid composition of *S. bicolor* and *S. vulgare* grain (% of total fatty acids)

	Sorghum vulgare	***Sorghum bicolor***			
Fatty acid	**NRC[1]**	**USDA 2009**	**Rooney & Serna-Saldivar 1995**	**Osman *et al.* 2000[2]**	***S. bicolor* Range of mean values**
12:0		0.19		0.22–1.17	*0.19–1.17*
14:0		0.25		0.10–2.27	*0.10–2.27*
16:0	17.80	11.19	14.3	14.21–17.92	*11.19–17.92*
16:1	4.77	0.80	1.0	1.56–2.83	*0.80–2.83*
18:0	0.96	0.96	2.1	1.51–2.89	*0.96–2.89*
18:1	28.29	26.52	31.0	32.16–37.34	*26.52–37.34*
18:2	35.92	35.91	38.29	38.29–44.29	*35.91–44.29*
18:3	1.91	1.79		1.04–1.65	*1.04–1.79*

[1] NRC - Nutrient Requirements of Poultry (1994) based on *S. vulgare*

[2] Analysis of six cultivars of *S. bicolor*

B. Forage sorghum

18. The leaves and stalks of *Sorghum bicolor* may be harvested and fed as hay or straw, or animals may be grazed on stover after the grain has been harvested. Broom sorghum (*S. vulgare*) and sudangrass (*S. sudanense*) may be grazed, or whole plants may be harvested for forage as green chop, silage, or hay. The leaves and stalks of brown midrib mutant (BMR) varieties of *S. bicolor* are reported to have lower lignin concentrations compared to cultivars lacking this trait, making them a more desirable roughage source for livestock. However, the data on fibre fractions, particularly lignin, vary among the available

published sources, and methods used to conduct analyses are not always reported. Table 7 compares the nutrient composition of silage from several sorghum species.

Table 7. Nutrient concentrations of silages produced by *S. bicolor*, BMR mutant *S. bicolor*, Sudangrass (*S. sudanense*) and the hybrid *S. bicolor* BMR x *S. sudanense*

Nutrient	***Sorghum bicolor***[4,5]	***S. bicolor* BMR mutant**[5]	***S. bicolor Range of mean values***	***Sorghum sudanense***[4]	**BMR x *S. sudanense***[6]	***S. sudanense Range of mean values***
DM, %	28.8–30.0	30.0	*28.8–30.0*	28.8	28.2	*28.2–28.8*
(% of DM)						
Crude Protein	7.3–9.1	7.9	*7.3–9.1*	10.8	10.8	*10.8*
Ash	7.5		*7.5*	10.9	7.64	*7.64–10.9*
Total Fat	2.9		*2.9*	3.6	3.9	*3.6 –3.9*
ADF[1]	36.6–38.7	39.8	*36.6–39.8*	40.7	41.6	*40.7–41.6*
NDF[2]	59.0–60.7	60.4	*59.0–60.7*	63.3	66.2	*63.3–66.2*
Lignin	6.5–10.3	7.5	*6.5–10.3*	5.9	4.6	*4.6–5.9*
NSC[3]					5.8	*5.8*

[1] Acid detergent fibre

[2] Neutral detergent fibre

[3] Non-structural carbohydrate = 100 - (ash + total fat + crude protein + neutral detergent fibre)

[4] NRC - Nutrients Requirements of Dairy Cattle (2001)

[5] BMR - brown midrib mutant of *S. bicolor:* Grant *et al.* (1995)

[6] Dann *et al.* (1988)

19. Very little information is available on mineral composition of forage sorghums. Macro and micro-mineral contents of silages produced from *S. bicolor*, *S. sudanense*, and the BMR mutant of *S. bicolor* x *S. sudanense* hybrid are presented in Table 8.

Table 8. Mineral composition of sorghum silages from *S. bicolor*, Sudangrass (*S. sudanense*) and the hybrid *S. bicolor* BMR x *S. sudanense*

Mineral	***Sorghum bicolor***[1]	***Sorghum sudanense***[1]	**BMR x *S. sudanense***[2]
(% DM)			
Ca	0.5	0.64	0.66
P	0.21	0.24	0.20
Mg	0.27	0.31	0.39
K	1.75	2.57	1.87
S	0.12	0.15	0.12
Na	0.02	0.03	0.01
Cl	0.6	0.56	1.07
(mg/kg)			
Fe	392	990	518
Zn	31	33	24.0
Cu	9	11	9.0
Mn	65	79	79.0
Mo	1.9	2.7	0.8
Se	0.03		

[1] NRC - Nutrients Requirements of Dairy Cattle (2001)

[2] Dann *et al.* (1988)

C. By-products of sorghum processing

20. The by-product of sorghum ethanol production is distillers' grains. Data on distillers' grains are available (Lodge *et al.* 1997, Al-Suwaiegh *et al.* 2002), but are somewhat limited in scope. Table 9 presents the available nutritional information for wet and dry sorghum distillers' grains, and dry grains plus solubles. Distiller's dried grains with solubles (DDGS) contain all fermentation residues, including yeast, remaining after ethanol is removed by distillation (Shurson, 2009).

Table 9. Nutrient composition of sorghum distillers' grains

	Wet distillers'	**Dry distillers'**	**Dry distillers' + solubles**
DM, **%**	23.5–35.3	91.4	91.4
(% DM basis)			
Crude Protein	31.2–31.6	32.9	31.4
Ash	2.5		
Total fat	11.3–13.3	13.0	11.8
ADF	28.5	28.4	
NDF	41.3–45.4	45.8	51.1
NSC[1]	9.2	3.3	
Starch[2]	10.2		7.4

[1] Non-structural carbohydrate, expressed as 100 - (ash + ether extract + crude protein + neutral detergent fibre), from Al-Suwaiegh *et al.* (2002)

[2] expressed as starch, although method not provided, from Lodge *et al.* (1997)

21. By-products of sorghum starch extraction include bran, sorghum hominy, sorghum gluten feed, sorghum gluten meal, and oil meal. Very little nutritional information is published on these by-products. The FAO-AFRIS has published nutrient compositions for several of these feedstuffs, but most of the values are based on data from 1970. In the absence of more recent data, Table 10 provides available information as a general guideline. As mentioned in the previous section, sorghum starch production is limited, and so it is expected that by-products of sorghum starch production will not be widely available.

Table 10. Nutrient and essential amino acid composition of by-products of sorghum (*S. bicolor*) starch extraction

Measurement	**Bran**	**Hominy**	**Gluten Feed**	**Gluten Meal**	**Oil Meal**
Moisture, **%**	12.0	11.0	10.5	10.7	0.9
% DM basis					
Crude Protein	8.9	11.2	24.6	46.9	16.6
Ash	2.4	2.7	8.2	3.8	1.6
Total Fat	5.5	6.5	4.9	7.2	7.8
Crude Fibre	8.6	3.8	9.5	5.3	13.2
NFE[1]	74.6	75.8	52.8	36.8	60.8
Arginine			0.111	0.145	0.108
Cystine			0.054	0.080	0.055
Glycine			0.138	0.145	0.123
Histidine			0.069	0.103	0.066
Isoleucine			0.096	0.235	0.081
Leucine			0.273	0.835	0.176
Lysine			0.054	0.066	0.055
Methionine			0.054	0.103	0.066
Phenylalanine			0.111	0.314	0.095
Threonine			0.111	0.145	0.081
Tryptophan			0.015	0.038	0.136
Tyrosine			0.081	0.235	0.055
Valine			0.192	0.286	0.123

[1] Nitrogen-free extract, expressed as 100 - (ash + ether extract + crude protein + crude fibre)

SECTION III – ANTI-NUTRIENTS

A. Cyanogenic glycosides

22. Cyanogenic glycosides are mainly present in germinating seeds, sprouts and the leaves of immature sorghum plants. Traore *et al.* (2004) showed that malted red sorghum that had been dried contained on average 320 ppm cyanogens. The most abundant of cyanogen is dhurrin, which may comprise three to four percent of the leaves of germinating seeds (Waniska and Rooney, 2000). Stressors such as drought, frost, heavy insect infestation, or overgrazing can result in increased levels of these compounds, which, along with tannins, are part of the plants' defence mechanisms. The use of potassium nitrate fertilizer was also shown to increase cyanogen production in sorghum (Busk and Moller, 2002). In the stomach of livestock, cyanogenic glycosides may be converted into hydrogen cyanide, which is very toxic, and at low level chronic exposure may result in poor growth or reduced milk production.

23. Although sprouted sorghum can contain high levels of cyanogens, typical methods of processing sprouted sorghum grain for human consumption, such as manual degermination (removal of roots and shoots) removes most the toxin (Traore *et al.*, 2004; Dada and Dendy, 1987). Therefore, cyanogenic glycosides are not generally a concern for humans. Malted sorghum is commonly used in the production of beer and other beverages and baked goods in Africa, which are consumed without resulting health problems associated with the formation of low levels of hydrogen cyanide (Waniska and Rooney, 2000).

24. Processing of germinating seeds for feed may result in the release of cyanide. It is generally recommended not to graze animals on young plants or cut them for green chop until they are at least 18 to 51 cm tall (Undersander and Lane, 2001). However, traditional curing processes such as drying for hay, and malting processes of sprouts such as heating and drying, reduces the concentration of this toxin below a level of concern (Dada and Dendy, 1987; Waniska and Rooney, 2000). With proper management, such as waiting until the plants have reached an appropriate height before grazing or harvesting, appropriate stocking rates, and good growing conditions, the levels of these compounds are low and do not pose a risk to livestock. Sorghum varieties developed specifically for grazing (*e.g.* Sudangrass) have low or non-detectable levels of cyanogenic glycosides (Waniska and Rooney, 2000).

B. Tannins

25. Early literature identified tannic acid as an anti-nutritional factor in sorghum grain. However, more recent research indicates that tannic acid is not a sorghum component (Dykes and Rooney, 2006). Some, but not all, sorghum varieties have pigmented testa containing condensed tannins, polyphenolic compounds that possibly give the seed a bitter taste and have been known to reduce intake, digestibility (particularly of protein), growth, and feed efficiency of livestock (Gilani *et al.* 2005; Waniska and Rooney, 2000). Sorghums are classified based on their tannin content: type I, no detectable tannin; type II, tannins in pigmented testa; type III, tannins in pigmented testa and pericarp (Waniska and Rooney, 2000).

26. Digestibility and utilization of absorbed nutrients may be reduced 3-15% by tannins (Waniska and Rooney, 2000). Tannins act as a plant defence against consumption by birds, and also provide some resistance to mold. In livestock production, tannins reduce the availability of key nutrients such as protein,

energy, vitamins and minerals. Tannins are associated with the outer layers of the pericarp and testa of the sorghum kernel. White sorghum varieties without a pigmented testa are free of tannins. Red, brown, or black varieties may contain significant amounts of tannins, but only if they have a pigmented testa.

27. The preferred method to determine if sorghum grains have a pigmented testa and hence contain tannins is to perform a “Clorox” bleach test as described by the International Association for Cereal Science and Technology (ICC, 2008). This test, a standard analysis method of the ICC, is used by the Federal Grain Inspection Service of the United States (USDA, FGIS-GIPSA) in classifying sorghum. Decortication of sorghum grain is sometimes made to remove or reduce tannin content (Waniska and Rooney, 2000).

C. Phytic acid

28. Like all grain species, sorghum contains phytic acid which binds minerals and reduces their availability to the consumer. Its phytic acid levels are similar to those reported for wheat, barley and maize, but lower than that of soybeans and other oilseeds. Since sorghum grain is usually low in mineral content (with phytin and mineral contents equivalent to maize), and the presence of phytic acid likely rendering its low mineral content unavailable, supplementation with other mineral sources is necessary where sorghum is a major component of the diet. As with tannin content, phytic acid content (and mineral content) may be reduced by abrasive decortication of the grain to remove the pericarp and aleurone layers (Waniska and Rooney, 2000).

D. Enzyme Inhibitors

29. Sorghum contains protease inhibitors that specifically inhibit serine proteases such as trypsin and chymotrypsin, and most varieties also contain α-amylase inhibitors. These inhibitors are potent antifungal agents and are inactivated by germination and heat treatments (Waniska and Rooney, 2000).

30. Concentrations of anti-nutrients in sorghum sprouts and grain as reported in available literature are summarised in Table 11.

Table 11. Concentrations of anti-nutrients in sorghum sprouts and grain

	Unit	**Grain**				**Sprouts**	
Anti-Nutrient		Waniska & Rooney 2000	Salinas *et al.* 2006	Kayode *et al.* 2007	*Range of mean values*	Waniska & Rooney 2000	Traore *et al.* 2004
Cyanogens	(ppm)		---	---		613	320[1]
Tannins	(g/100g DM)		0.55–1.05	0.22	*0.22–1.05*		
Phytic Acid	(g/100g DM)	0.17–0.38		0.80	*0.17–0.80*		

[1] based on dried sprouted seed

SECTION IV - SUGGESTED CONSTITUENTS TO BE ANALYSED RELATED TO FOOD USE

A. Key products consumed by humans

31. Consumption of sorghum as food has been increasing since the early 1980s, particularly in the more arid regions of developing countries in Africa, Asia, the Caribbean, and Central and South America. Eaten in a variety of forms depending on the region, sorghum may be consumed as whole grain, popped as a snack or boiled into porridge, processed into flour for baking, or fermented to produce beer or other baked goods. According to the Encyclopedia of Life Support Systems (UNESCO-EOLSS website), the main sorghum-based foods are: flatbread (unleavened and prepared from fermented or unfermented dough); fermented or unfermented porridges, couscous, grits; fermented or unfermented beverages; deep-fried preparations, and many others. Sorghum may also be used alone or in combination with maize to produce tortillas.

32. Sorghum flour used for baking does not contain viscoelastic gluten, such as that found in wheat, barley and rye doughs. Although this makes sorghum flour acceptable for use in products for patients with celiac disease (Ciaci *et al.*, 2007), yeast-leavened products from 100% sorghum flour are difficult to obtain (Waniska and Rooney, 2000), and may have undesirable characteristics such as poor rising, coarse crumb, and brittleness (Taylor *et al.*, 2006). Addition of gums, starch, enzymes, emulsifiers, and fat sources improve the quality and texture of sorghum breads, and using a soft batter rather than firm dough also improves quality of leavened breads (Taylor *et al.*, 2006). Unleavened breads, tortillas, and snacks are successfully produced with 100% sorghum flour and mixtures of sorghum and maize flour (Waniska and Rooney, 2000; Taylor *et al.*, 2006).

33. Malting and brewing of sorghum has been used to produce lager, stout (referred to as “clear beers”) as well as traditional opaque beers in parts of Africa (Taylor *et al.*, 2006). The basic process for producing beer involves making gruel of cooked, gelatinized starchy adjunct which is then liquefied and saccharified by enzymes in a malted cereal (Daiber and Taylor, 1995). The malting process involves soaking viable grain and allowing it to germinate under conditions that permit activation of enzyme systems while minimizing respiration losses. Sorghum starch has a higher gelatinization temperature and lower β-amylase activity in the malt compared to barley. If tannins are present in the sorghum, they can inactivate amylases and the sorghum has to be chemically treated to inactivate the tannins (Taylor *et al.* 2006). Thus, various modifications in brewing clear beer have been developed to overcome these limitations, including the use of sorghum only as a starchy adjunct, use of barley malt or commercial enzymes to hydrolyze sorghum starch, and potentially the use of waxy (high amylopectin) sorghums rather than normal sorghums in the malting and brewing process (Taylor *et al.*, 2006).

B. Suggested analyses for food use

34. Sorghum’s primary contribution to the human diet is energy in the form of starch and proteins. The protein content of sorghum varies across varieties, and, like many grains, is low in essential amino acids, particularly lysine and threonine. It has slightly more tryptophan than maize. However, complementary proteins from legumes can meet dietary requirements for these amino acids (Klopfenstein and Hoseney, 1995).

35. Sorghum is not an important source of fatty acids, minerals or fat-soluble vitamins; however, it does contain reasonably high amounts of choline and vitamin B6. Although sorghum appears to have relatively high levels of niacin, the availability of this vitamin is questionable. The availability of these nutrients for absorption depends on the processing of the kernel and the concentration of tannin in the grain. Traditional forms of processing (steeping, parboiling, fermentation, malting, popping, roasting, drying, alkali or acid treatment, and milling) may make starch and protein more available, but some of these methods will destroy vitamins thereby reducing the concentration of certain vitamins.

36. Tannin content should be estimated qualitatively in whole grain and sorghum bran. Methods for estimating tannin content are described by the ICC (ICC, 2008).

37. Constituents suggested for analysis in grain sorghum for food and beverage use are listed in Table 12. When one considers all of the sorghum products that might be used as human food, their nutrient content should not be expected to change if the content of the whole seed is not changed. Hence, only the whole grain sorghum seed are suggested to be analyzed.

Table 12. Suggested constituents to be analysed in grain sorghum (*S. bicolor*) for food use

Parameter	**Whole grain**
Moisture	X
Crude Protein	X
Crude Fat (Ether Extract	X
Ash	X
Total Dietary Fibre	X
Starch	X
Fatty Acids	X
Amino acids	X
Tannins	X
Phytic acid	X
Pyridoxine (Vit B6)	X

SECTION V - SUGGESTED CONSTITUENTS TO BE ANALYSED RELATED TO FEED USE

A. Key products consumed by animals

38. Most parts of the sorghum plant are used as animal feed. Growing sorghum may be grazed, or the aerial parts of the plant may be ensiled or dried and fed as stover or silage for ruminant animals. Whole sorghum grain is cracked, ground, or steam flaked and fed to poultry, swine, dairy and beef cattle as a source of energy. Although not common, by-products of sorghum starch extraction such as hominy and gluten feed or gluten meal may also be fed to livestock. The Association of Animal Feed Control Officials in the United States (AAFCO, 2009) defines sorghum gluten feed and gluten meal as follows:

39. Grain Sorghum Gluten Feed is that part of the grain of grain sorghums that remains after the extraction of the larger part of the starch and germ, by the processes employed in the wet milling manufacture of starch or syrup.

40. Grain Sorghum Gluten Meal is that part of the grain of grain sorghums that remains after the extraction of the larger part of the starch and germ, and the separation of the bran by the processes employed in the wet milling manufacture of starch or syrup.

Note: Milo, Hegari, Kaffir, or Feterita may substitute for the words “grain sorghum” in the above-mentioned definitions. If the name of the type is given, it must correspond thereto.

B. Suggested analyses for feed use

41. As mentioned previously, nutritional composition of sorghum grain and stover varies with environmental conditions. However, some standard analyses for nutrient composition may be warranted.

42. Proximate analysis is typical for feed ingredients for non-ruminants. This analysis typically includes moisture, crude protein (N x 6.25), crude fibre (composed of cellulose, hemicellulose and lignin), fat (expressed as ether extract), and ash. Nitrogen-free extract (dry matter basis) includes starch, sugars, and the soluble fraction of hemicellulose, and is derived by difference [100 - (Crude P + Crude Fibre + ether extract + ash = NFE)]. Starch may also be analyzed directly, and this may be preferred for whole grain and bran, as NFE may also include hemicellulose, cellulose and lignin, which are indigestible for non-ruminants. Another means of expressing soluble carbohydrates is NSC, also derived by difference [100 - (crude protein + ether extract + ash + neutral detergent fibre)]. For proximate analysis of animal feeds, acid-detergent fibre (ADF) and neutral detergent fibre (NDF) are preferred to crude fibre analysis, particularly for ruminant feeds. These give an improved indication of the digestibility and the energetic feeding value of the feed, which is particularly important. Amino acids and fatty acids should be individually quantified. Among the fatty acids, linoleic is of key importance for sorghum grain.

43. Tannin is the major anti-nutrient of concern in sorghum grain products, particularly bran, in varieties that contain tannins. As mentioned above, analyses to estimate tannin content are available and not difficult to perform (ICC, 2008).

44. Phytic acid is common to all grains. With the use of the enzyme phytase, it is possible to break down part of the phytic acid and release bound phosphorus and calcium. Hence, the phytic acid content of the grain is beneficial to know.

45. As hydrogen cyanide poisonings have been reported in livestock grazing sorghum stubble (Waniska and Rooney, 2000), cyanogenic glycosides should be quantified.

46. Constituents suggested for analysis in grain sorghum for feed use are listed in Table 13. When one considers all of the sorghum products that might be used as animal feed, their nutrient content should not be expected to change if the content of the whole seed and the whole plant is not changed. Hence, only the whole grain sorghum seed or the whole sorghum plant are suggested to be analyzed.

Table 13. Suggested constituents to be analysed in grain sorghum for feed use

	Whole grain	**Whole plant**
Moisture	X	X
Crude Protein	X	X
Crude Fat (Ether Extract)	X	X
Ash	X	X
ADF	X	X
NDF	X	X
Amino acids	X	
Fatty acids	X	
Calcium	X	X
Phosphorus	X	X
Tannins	X	
Phytic acid	X	
Cyanogenic glycosides		X

SECTION VI – ABBREVIATIONS USED

ADF	Acid Detergent Fibre, an estimate of cellulose and lignin content
BMR	Brown midrib mutant of *Sorghum bicolor*
CIS	Commonwealth of Independent States
CGIAR	Consultative Group on International Agricultural Research
CP	Crude Protein (N x 6.25)
DM	Dry Matter
FAO	Food and Agriculture Organization of the United Nations
FGIS-GIPSA	Federal Grain Inspection Service-Grain Inspection, Packers and Stockyards Administration (United States)
GRIN	Germplasm Resources Information Network, USDA, Agricultural Research Service, a database on taxonomy for plants
ICC	International Association for Cereal Science and Technology
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
ITIS	Integrated Taxonomic Information System (North America)
NDF	Neutral Detergent Fibre, an estimate of cell wall content
NFE	Nitrogen-Free Extract, derived by difference [100 - (crude protein + crude fibre + ether extract + ash)]
NRC	National Research Council of the United States
NSC	Non-Structural Carbohydrate, derived by difference [100 - (crude protein + ether extract + ash + NDF)]
UNESCO	United Nations Educational, Scientific and Cultural Organization
USDA	United States Department of Agriculture

SECTION VII – REFERENCES

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