Utilization of Sorghum and Millets

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Composite Flour—Past, Present, and Future: A Review with Special Emphasis on the Place of Composite Flour in the Semi-Arid Zones

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Abstract

The use of blends of wheat and nonwheat flours, known as composite flour, became prevalent when wheat was scarce. Since the 1960s, much research aimed at incorporating nonwheat material of local origin on bread and other flour products was undertaken, thus limiting wheat imports. Because the Government of Nigeria has banned wheat imparts, this technology is no longer relevant. Opportunities exist for composite flour where wheat is available locally or can be imported without undue economic constraints, and where local cereal flours can be blended into wheat flour for breadmaking. The technology is available, and composite flour programs should be part of national policies on sorghum and millets. Opportunities also exist for blending indigenous cereals into products from exotic grains such as maize.

Introduction: The Bread Economy

Many countries in the Third World have become heavily dependent on staple foods which they import and for which conditions for local production are poor or nonexistent. Once established, such a dependent consumption pattern is self-reinforcing (Andrae and Bechman 1985).

One could add that both the food and the food habit are imported. Not only improved grains such as wheat should be considered, but nonindigenous grain crops such as maize which were imported earlier and are now established, although they are less suited to harsh climates than indigenous sorghum and pearl millet.

To understand the importance of composite flour in developing countries, one must first understand how the bread habit was acquired.

The essential ingredient of bread is wheat—more particularly, the unique wheat protein known as gluten. Wheat originated in the Vavilov Center between the Caspian Sea, the Black Sea, and the Mediterranean. In Roman times wheat was traded in Britain and elsewhere, but it was not until the nineteenth century that wheat and flour were traded to places where wheat had not previously been grown: tropical regions colonized by the European powers. Freed slaves from Brazil undoubtedly also played a part in the establishment of the bread habit in parts of West Africa during this period.

The bread habit, derived in part from the convenience and wholesomeness of bread, was sustained by vigorous advertising of bread as a convenient and upmarket food. Unfortunately, bread must be purchased with hard currency. Countries with wheat surplus are anxious to establish and maintain markets, particularly in the face of declining markets in Europe and North America. In most developing countries there are flour mills, many of them recently built, to process this wheat and thus sustain the bread habit. Fur-

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thermore, when famines occur, wheat is often donated or sold below production cost to ameliorate the deficit of local staple foods. In Bangladesh, for example, after wheat was donated during the famines of the early 1970s, a massive effort to grow wheat as a second (winter) crop was undertaken to satisfy the wheat-eating habit (mainly as chappatis rather than bread). Previously, wheat production in Bangladesh had been less than 1% of total cereal production: it is now over 5%.

In developing countries, a simple correlation exists between the increase in urban population and the increase in wheat imports (Edmunds 1970)—each is about 10% per annum.

The habit of eating bread also spread as a result of improvements in the transport infrastructure. Possibly, the best documented case study is that of Nigeria (Andrae and Bechman 1985). In 1965 Kilby wrote a book on Nigeria's locally owned bakeries. At that time wheat and flour imports totaled only 56 000 t—0.4% of the total carbohydrate-based diet (cereals plus root crops, expressed as 20% harvest weight). With new oil revenues enabling large purchases of wheat and investment in mills and bakeries, imports increased very rapidly, from 0.41 million t in 1975 to 1.67 million t in 1984—a total of 13.3% of Nigeria's cereal plus root-crop diet. Meanwhile, wheat production increased from 15 000 t in 1965 to 45 000 t in 1985, still only 2.7% of wheat consumption. It should also be noted that the cost in foreign exchange of this local production was extremely high, as wheat can only be grown with irrigation in the cool dry season. Andrae and Bechman (1985) concluded that the economic justification for wheat production in Nigeria was fraudulent. The illusions of the millers and wheat traders were shattered in January 1987 when the ban on wheat imports came into effect. With a single stroke Nigeria stood to save up to US$ 500 million per annum.

It is ironic that although the Nigerian Federal Institute for Industrial Research at Oshodi has worked on composite flour for many years, (i) no industrial uptake and little interest was shown by millers or bakers, (ii) no Government policy was developed, and (iii) the will to implement composite flour technology was lacking.

Composite Flours: History and Concept

This papers deals with the subject of composite flours, which may be considered as either:

a. a combination of wheat and nonwheat flours for the production of leavened breads, [illegible] baked products, and pastas; or
b. a wholly nonwheat flour prepared from mixtures of flours from cereals, roots, tubers, legumes, or other raw materials, to be used for traditional, western, or novel products.

Because the latter definition is too general to be of practical use, composite flour is usually thought of in terms of (a).

Nigeria is an extreme example of the bread habit corrupting an economy: only developing countries with vast mineral or oil wealth can afford such a massive change in diet, with the ensuing problem of sustaining an imported food habit after the wealth has gone. The situation in Nigeria therefore provided a prima facie case for the use of composite flours. The desirability of diluting wheat flour with locally available cereals and root crops (with the possible addition of a protein supplement) was clear. If successful, this development will encourage the local agricultural sector and lessen wheat imports at the same time.

Making bread by substituting part of the wheat is not a new idea. In ancient times, the most frequently used diluent was barley, and often bread containing large amounts of barley was the staple food of the poor. In Britain, barley, rye, oats, and sometimes beans were added to wheat flour, which in most years was too dear for the common people. Bran was frequently added to whole wheat flour for the poor to satisfy the demand for white flour of the wealthy (Drummond and Wilbraham 1957). By the end of the nineteenth century, Britain was importing large quantities of wheat from North America, domestic supplies having become too small for its large industrial population. When scarcity resulted during the First World War, imports were reduced. As in previous times of scarcity, it became necessary to add nonwheat materials to bread. Barley, which grows well in Britain, was chosen as the principal diluent. At first only 5% of the diluent was added to the wheat, but the quantity was gradually increased and by the end of the war, bread frequently contained about 20% "adulterant" and the wheat flour itself was at or above the 90% extraction rate. The emotive term "adulteration" is still used by millers and bakers who oppose composite flour programs. During the Second World War these mixtures were again used and today, during times of temporary scarcity of imported wheat, local materials have been used as diluents in developing countries. It was not, however, until the 1960s that scientific interest in composite flours was aroused.

This interest came about for two reasons: firstly, recent discoveries in starch chemistry and baking technology made possible the use of composites and even of gluten-free products for baking; secondly, there was an upsurge in interest in the food problems of the newly emerging nations of the tropics.

Composite flour technology owed much of its initial impetus to Pierre Chatelanat and the FAO. Chatelanat noted that wheat flour was expensive in Papua New Guinea and persuaded FAO to request a preliminary study at Wageningen, the Netherlands, initially on the use of cassava in bread. Three international organizations were active in the early days of composite flour research: the Tropical Products Institute (TPI, now the Natural Resources Institute [NRI], UK), Kansas State University (USA), and the Institute for Cereals, Flour and Bread (TNO), Wageningen.

It was the latter institute which made the fundamental scientific discovery that awakened interest in the possibilities of composite flour. TNO researchers noted that dough (and therefore bread) structures could be formed using starch with surfactants such as glycerol monostearate (GMS). It was found that the crumb structure and volume of bread improved by adding these surfactants and that weaker wheats could be used while retaining conventional crumb structure and volume. The Wageningen work was subsequently transferred to Colombia, where bread containing 30% cassava starch was baked at the pilot scale. Work on wheatless bread, however, was less successful.

The Flour Milling and Bakery Research Association at Chorleywood, UK, developed a process in the early 1960s whereby flour with lower than normal gluten content could be used to make bread by mechanical dough development.

Hulse et al. (1969) wrote a brief report entitled "Mechanically Developed Doughs from Composite Flours" using the Chorleywood process to produce bread containing 30% nonwheat material. The work carried out at TPI followed from this work, and the Institute has since (as NRI) been involved in composite flour since 1969 (Dendy et al. 1970, Crabtree and James 1982).

Other teams began work shortly afterwards, and in 1972, when the first Composite Flour Bibliography was published by TPI, it included 160 citations. In spite of the vast amount of scientific and technical research, however, little had been published on the economics of composite flour. There was also very little published concerning actual implementation. Few technologies have been so thoroughly researched and so little applied.

One reason for this abundant research but lack of literature was that, to many research workers, composite flour was an ideal subject for academic research. It was easy to attract funding and to convince authorities that the subject was worthwhile. Students were able to carry out the research with minimal resources, frequently only basic kitchen equipment. Papers sometimes concentrated on organoleptic studies, comparing composite flour bread with the all-wheat product and demonstrating its acceptability in terms of flavor. Although actual consumer trials were rare, they were successful in Colombia, Kenya, Nigeria, Sri Lanka, and Sudan. Where laboratories were well-equipped, often with external resources, the quality of composite flour bread was much higher than that of local bakers working with crude equipment, lack of process control, and infested flour.

Because scientific journals are favorably disposed to publishing papers on composite flour, the illusion of original research is easy to maintain. By the time the Second Supplement to the Second Edition of the TPI Composite Flour Bibliography appeared in 1979, an impressive total of 952 papers had been published. There was still, however, little or no implementation.

Composite Flours: Current Position

Most of the composite flour research was carried out on cassava, a little on sorghum, and very little on millets. Table 1 summarizes some of the work over the past 20 years and gives some idea of the levels of nonwheat addition that can be expected and targetted.

With proper preparation, up to 30% sorghum or any one of the four most common millets (pearl, proso, foxtail, finger) can be used, either by preparing the flours first or by co-milling—a technique described by Crabtree and Dendy (1979). For preparing the raw materials from sorghum, pearl millet, and maize, one can use new technologies (such as the PRL or the Decomatic dehuller), conventional roller mills, or the semiwet milling technique developed at NRI (Cecil 1986). This latter technique is particularly appropriate in countries with a surplus of roller-milling capacity. Unfortunately, this capacity for milling sorghum, maize, or pearl millet is rarely embraced with enthusiasm: most of the mills are controlled by wheat traders and others with negative views on composite flour. When preparing a composite flour program it is therefore important that millers, bakers,

Table 1. Suggested levels for nonwheat moieties (as percentage of total flour) for composite flour bread (wheat urs were of various strengths).

			Millets			
	Sorghum	Maize	Pearl	Proso	Foxtail	Finger
TPI (NRI)	15-30	10-20	10-20	10-20	10-20	10-20
FRC Sudan	20-30	-	-	-	-	-
KSU	10	-	-	-	-	-
KIRDI	15-20	10-15	-	-	-	-
CFTRI	20	20	-	-	-	-
ITA	15-30	15	-	-	-	-
ECA compendium	15-20	20-25	15-20	-	-	-
Suggested maximum	30	25	30	20	20	20

Table 2. Wheat usage (1981-83) and possible savings by adoption of composite flour.[1]

	Kenya	Sudan	Tanzania	Zambia	Zimbabwe
Imports of wheat	150	230	35	140	100
Production of wheat	240	140	70	20	120
Total	390	370	105	160	220
Costing (at US$180 t^{-1})[2] delivered	27 m	41 m	6 m	25 m	18 m
Flour at 80% extraction	312	296	84	128	176
Non-wheat cereal flour (80% extraction) needed for 25% CF bread	104	99	28	43	59
Cereal	130	124	35	54	74
Possible foreign exchange savings (at US$180 t^{-1})	23 m	22 m	6 m	10 m	13 m
Trade deficit	304 m[3]	135 m[4]	350 m[5]	-	-
Sorghum production	180	1819	460	9	58
Millet production	80	314	335	13	100
Maize production	2178	50	1363	900	1023

1. Figures represent thousands of tonnes.
2. This figure fluctuates daily with the dollar, the wheat price, and the transport cost.
3. 1984.
4. 1985.
5. 1981.

and consumer organizations be brought into the discussions with Government at an early stage, since Government support is the first prerequisite.

The basic criteria for the raw materials are:

1. wheat flour of reasonable strength—preferably over 12% protein (N × 5.7); and
2. clean, fine flour from the nonwheat cereal free from specks of colored bran, compatible in color with wheat flour, and of as low a fiber content as possible.

Note that if it is necessary to add fungal amylase or diastatic malt to the flour to offset a high falling number (in Zimbabwe, for example), then sprouted sorghum or other cereal can be substituted as a locally available source of diastase.

Table 2 gives the tonnage of nonwheat cereal required for composite flour programs using a hypothetical 25% of nonwheat flours as the ultimate goal. Acceptable bread can be baked at this level, but if a higher proportion of nonwheat flour is used one can still bake bread (though not of a quality similar to all-wheat bread). The loaf volume would be lower, the crumb less open and more cake-like, and the color darker.

Composite Flours: Decision-Making Criteria

Kenya, Sudan, Tanzania, and Zimbabwe grow wheat, but they also import it to satisfy the difference between production and consumption. These countries also grow sorghum, pearl millet, and maize. The savings in foreign exchange are considerable. In addition, local agriculture is boosted by providing markets for the large quantities of nonwheat cereals needed. Even when there is no foreign exchange deficit, the foreign exchange currently spent on wheat could be cut and the money put to better use.

Within the wider definition of composite flour, the opportunities are vast. Blends of maize and sorghum meals can make excellent *ugali (sadza)*, provided the varieties used have similar cooking characteristics. Two incompatible varieties of maize can produce an indigestible and therefore unacceptable product, so it is the type of endosperm rather than the species which is important. Wheatless bread substitutes could also be made.

Crabtree and James (1982) published a paper outlining TPI's experience in composite flour and suggesting 10 requirements for implementation of the composite flour program.

> TPI considers that the use of composite flour in breadmaking offers scope for beneficial developments in many tropical countries but experience to date has been discouraging, largely because of the *lack of infrastructure* in the formulation of composite flour programmes. The Composite Flour technology has long since been proven.

The following steps are necessary to set up a program.

1. A technical study should be undertaken to determine the level of nonwheat substitution that may be achieved under local conditions. Because much knowledge is already in hand, this study need only take *weeks*, not months.
2. An economic study is essential to evaluate the balance between the savings on wheat imports and the investment needed for the purchase of processing and blending equipment if these are not available.
3. A definite decision must be taken by Government to proceed with a national implementation program followed by a formulation of policy.
4. Availability of appropriate varieties of the diluent grain must be assured to provide optimal quality characteristics for the composite flour products.
5. Seed multiplication and seed supply capacity must be assured.
6. A program of increased production of the nonwheat diluent and the provision of incentives to encourage farmers to grow the commodity are of paramount importance.
7. The selection and installation of processing and blending equipment should be undertaken with due regard for the necessary cooperation of the millers.
8. The training of bakers in the use of composite flour in breadmaking is recommended. This may not be necessary, but the bakers must be involved in discussions from the inception of the program.
9. A market survey on the acceptability of the composite flour bread and the education of the consumer are of key importance. Consumer organizations and the press must be won over early in the program.
10. The formulation of quality standards for the grain and for the composite flour must be defined.

A further effort in public awareness of composite flour was made in 1985 by the UN Economic Commission for Africa (ECA) in the "Technical Compendium on Composite Flours" (1985). This book describes the technologies available for application: some of which have been available since the early 1970s. Technologies for preparation of raw materials, which TPI recognized in the early 1970s as crucial, are given due prominence, as are sorghum and the millets.

Composite flour should not be considered a stop gap to be used only when a foreign exchange crisis arise. It should be built into national grain policies, provided bread consumption can be limited to those markets requiring a convenience food. Parallel to this but potentially of much greater importance to national agriculture is the development of markets for new and improved products from sorghum and millets—products with the convenience of bread combined with the appeal of tradition. New products created from old grains must be given greater emphasis.

Sorghum and pearl millet are the true staples of semi-arid Africa. Some countries already have established sorghum and millet working groups and a few have policies to encourage the cultivation of these crops. These policies should not only be designed to promote new and traditional foods based solely on sorghum and millets, but should, as long as wheat is available, have a place in a composite flour program. After all, composite flour technology is already available. In order to facilitate its successful implementation, the paramount requisite is political will. It is our duty to make sure that governments realize that the technologies for composite flour and for sorghum and millet utilization are available. Governments must implement composite flour programs and small grain utilization as part of their national food security strategies.

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Discussion

L.R. House: Should we not attempt to identify traits in sorghum and millets for which breeders could apply a selection pressure that would lead to a better flour for blending into wheat?

D.A.V. Dendy: Yes, but varieties are available now which can be milled into white flours of suitable qualities for inclusion in composite flour bread, as for example the cultivar Dobbs.

A.V. Obilana: Dr House's comment on specific varieties and specific traits is significant. At IAR, Samaru, Nigeria, we found specific differences in breads baked using sorghums with white or yellow endosperm and red sorghums mixed with locally grown wheat. These differences also showed up in the different sorghum:wheat ratios of composite flour. It is important to remember, however, that the development of policies geared towards backing such, local uses of sorghum and millets in baking nonwheat and wheat composite breads is still up to the Government.

R.E. Schaffert: Has any work been done on the variation between food-type sorghum cultivars regarding industrial processing such as mixing time? Our work has indicated that there is a difference.

D.A.V. Dendy and **J. Faure**: Different sorghum cultivars have different potentials for incorporation into composite flour. Milling quality, i.e, the ability of the grain to yield a fine white flour free from bran, is very important. Cultivars with vitreous endosperm may well give a clearer separation of bran from endosperm.

A. Carney: Has the scale of technology and replication on industrial scale been tested? Have we checked the composite flour usage in commercial-scale bakeries as well as mills, and have we replicated baking trials that show consistent results?

D.A.V. Dendy: Yes. Commercial-scale production was carried out in Colombia, Senegal, Sri Lanka, and Sudan. In the 1969/70 season, ODNRI worked with a commercial bakery in the UK to prove that the composite flour doughs were machinable. Laboratory studies should use Farinograph as well as test baking to give advice concerning mechanical problems that might arise.

A.C. Moshe: How do we win over the politicians and sell them the idea of composite flour?

D.A.V. Dendy: I do not know. We all should explore this. Economic analyses and presentation of facts to influence policy will help to counter the lobbying by opposing bakers.

O. Koleoso: The way to convince millers to use composite flour commercially is through economic squeeze, like in Nigeria. Also, the use of cassava in composite flour has been carried out in Nigeria and a substitution of 20% is adequate.

R. Jambunathan: You have shown 80.1% extraction rates for wheat and nonwheat cereals. Is this practically feasible?

D.A.V. Dendy: Yes. For wheat one can mill at anything from 60% to 100%. For sorghum, some varieties give rather low rates (e.g., broomcorn sorghum – see the 1977 Dada/Dendy report), but for white and yellow cultivars and for red cultivars like Dobbs, 80% should be attainable on a commercial mill, since we can get 70% in our Bühler 202 lab mill.

J.M. Mwale: Probably one way of getting political will is to ensure that we get more scientists into political positions. Our experience has been that once we have a minister who has some scientific background, we do not need too much persuasion to get economic backing. A corollary should be that we try to ensure good reporting from journalists on scientific information; otherwise the reporting on scientific matters is usually carried out from a political rather than a scientific point of view.

Discussion Spreadsheet - Primary Food Processing - Group I

		Level of application		
Process	Product	Research	Research and development	Industrial applications
1. Immature whole grain—roasting, boiling, popping, steaming, flaking	Roasted/boiled, puffed, steamed, flaked (Ethiopia, India, Uganda)	Processing research	Intermediate technology, for small-scale applications	Traditional
2. Whole grain composite, boiling/popping	Sorghum + legume (Nigeria)	-do-	—	Traditional
3. Whole (dry) grain roasting and grinding	Roasted grain (India, western Tanzania), Roasted dry flour (Zimbabwe)	-do-	—	Traditional
4. Whole grain treatment: acid/alkali/ash (AAA)	AAA treated grain (western Africa, Uganda)	—	—	Traditional/ rural (western Africa, Uganda)
Whole grain treatment: formaldehyde (pretreatment in brewing)	—	—	—	Formaldehyde in malting/ brewing)
Steeping	—	Acidulants and alkaline agents	—	—
5. Dehulling whole grain traditionally	Pearled grain + bran, kibbled grain (like mealie rice), boiled products	—	Small-scale	Traditional
6. Dehulling + pounding (grinding) traditionally	Meal (porridge) + bran.	Low level	—	Traditional
7. Dehulling (mechanically)	Pearled grain + bran (rice analog)	Optimizing technology Varietal screening	—	Semi-industrial (Africa. Asia)
8. Dehulling, dry milling (hammer, roller) Other milling systems (e.g., UMS Decomatic)	Meal, offals (bran, etc.), flour and milled fraction, flour (refined)	-do-	Optimizing a milling system for small grains	Semi-industrial (SADCC region) Industrial (Nigeria)

tritional plications	Sustainability	Future work	Priority (1 = high, 5 = low)
gh lysine varieties onsumed as immature/ ilk dough grain Ethiopia	Western Africa, Ethiopia	Breeding and processing research—explore use in special foods (e.g., weaning food)	5–SADCC region (especially Zimbabwe) 3–Western Africa, Ethiopia, India
mplementary protein and mino acid balance	Botswana, Lesotho, Nigeria, Tanzania, Zimbabwe	Dissemination of nutritional advantages, commercial applications (e.g., *soyogi*)	1
proved digestibility (?)	Snack food, school feeding	Explore industrial scale-up	5–SADCC region and global until more research is available
eduction of phenols and annins, improved utritional quality	Yes	Scale-up of industrial application permitting use of high-tannin varieties for food	1
o	Yes	-do-	1
eduction of tannins (?)	Yes	Research on nutritional and processing quality	More information needed
creased palatability	Yes, but constrained by labor input	Grain characteristics for better dehulling (e.g., thick pericarp vitreous endosperm) Principles of traditional dehulling, conditioning, impact dehulling to loosen hulls to be researched as alternative to abrasive dehulling	1
ncreased palatability, keeping quality of millet	Yes	Research on breeding and on processing quality, especially for millets	3–sorghum 1–millets
ncreased palatability, convenience	Potential subject to pricing policies (Sudan)	Grain characteristics (thin pericarp, vitreous endosperm). Value adding to bran—some bran fractions suitable for human food (good protein, fat, and energy content) Rice analog, more research	
	Dehulling, hammer milling (porridge meal)	Feasibility/viability of commercial mills in urban areas: breeding research, milling quality	2

Discussion Spreadsheet - Secondary Food Processing - Group II

		Level of application		
Process	Product	Research	Research and development	Industrial applications
1. Compositing/ blending	Bread, cookies, biscuits, pastas	Technology known (FAO/ECA, ODNRI, IRAT FIIRO, FRI, Sudan, ITA)	Yes	Yes, up to 10% in Zimbabwe (5% sorghum and 5% maize), possibly 25% potential for other SADCC countries
2. Nonwheat flour	Nonwheat bread, cookies, pastas	Little information	Research and development experimentation (Nigeria)	Potential for industrial application (Nigeria)
Dehulling/milling (composite or 100% small grain)	Porridge bases (thick/thin), dumplings	–	Yes (Botswana, Zimbabwe)	Traditional/industrial products
Agglomeration	Agglomerates (beverage base)	–	–	–
3. Fermentation	Clear beer	Technology known, subject to proprietary secrecy (e.g., malted beverages and brewing research in Nigeria)	Yes (Nigeria, Mexico)	Quality standards and processing technology for available analogs (e.g., milo) Semi-industrial quality criteria important (Nigeria)
	Opaque beer	Technology known	–	Africa
4. Acid fermentation	*Mahewu* (Zimbabwe) *Ting* (Botswana) *Uji* (Eastern Africa)	Technology known	–	Commercial (Botswana, Kenya, Lesotho), not as successful as formerly in Zimbabwe
5. Conversions from starch (chemical/ enzymatic)	Glucose, dextrins	Not available (Starch extraction from small grains more difficult than from maize or tuber crops)	Nigeria? Grain quality for starch extractability (India, Mexico, Sudan)	–
6. Formulations (cereal binders extenders)	Meat products (sausage, rusk)	Available (FIIRO, KIRDI, ODNRI)	Nigeria (FIIRO), Zimbabwe	Industrial potential exists
7. Starch hydrolysis (alcohol, acetic acid) sorbitol	Alcohol, acetic acid, citric acid,	As for (5)	As for (5)	As for (5)
8. Modification of starch	Modified starches	As for (5)	As for (5)	As for (5)

	Sustainability			Priority (1 = high, 5 = low)
tritional plications	Yes	No	Future work	
lehulled rotein upplementation ith soya, etc.	Process sustainable	Product sustainability subject to ploicy/ pricing	More research needed on food quality, varieties, technology optimization for local seeds	1-SADCC
tial eplacement f wheat	Not applicable	–	Quality requirements of raw material and products Research on cultivars, especially for mixtures (ICRISAT, Tanzania) Research on milling and food quality (ICRISAT, ODNRI, Tanzania)	1–Botswana, Lesotho, Tanzania 2–Other SADCC countries 5-Zimbabwe
–	–	–	–	1-Botswana, Lesotho, Tanzania 2-Malawi 3-Other SADCC countries 4-Zambia, Zimbabwe
–	–	–	–	–
nportant	Not applicable (product and process sustainable)	–	Acceptable varieties/ cultivars with required grain quality	1-SADCC generally 2-Tanzania 5-Zimbabwe
ot adequately esearched	Process and product sustainable	Affected by pricing/ excise policy	Breeding and selection implications	1-SADCC 3-Zimbabwe
nportant as food and beverages	Yes (commercial product declined in Zimbabwe)	–	Quality improvement	1-SADCC, as weaning food 2-SADCC, as beverages
–	Yes, potential only in small grain surplus countries (Zimbabwe, Malawi, Tanzania, Kenya)	No, in cereal-deficient countries (Botswana, Zambia, Mozambique, Angola, Lesotho)	–	5-SADCC generally
–	–	–	Selection of cultivar, use of reds, color not a problem	3-SADCC
As for (5)	Depends on viability of starch extraction and market demand	–	–	–
s for (5)	Depends on viability of starch extraction and market demand	–	–	5-SADCC generally

Discussion Spreadsheet–Industrial Uses–Group III

		Level of application		
Process	Product	Research	Research and development	Industrial applications
1. Sweet sorghum milling	Sugar juice, raw sugar, brown sugar, alcohol, bagasse (feed, fuel, cellulose)	Under study and development	Continuing	Started
2. Wet milling (grain)	Starch, sweeteners, syrup, sizing chemicals	Research complete	–	Yes, but not currently economical in USA
	Protein and oil fiber (dietary)	Depends on research on protein, oil, and fiber interactions	–	No, only if starch is economical
3. Dry milling (grain)	Industrial starch and flour, adhesives, core binding, ore refining	Research and technology available in USA and other countries	Yes	Yes, in USA, need to develop market, good potential
4. Dry milling (stover/straw)	Fuel pellets (from fines/waste), particle board	Research complete for other cereal straws (Denmark, USA) Research on going for sorghum and millets	Continuing	Yes, as for other cereal straws
5. Fermentation (sweet sorghum)	Alcohol (ethanol), stillage	Yes	Brazil	Yes, viable microdistilleries exist (Brazil)
	Biogas, biofertilizer	Yes	Brazil, India	Domestic village scale
6. Malting	Industrial enzyme from malt	Yes	Continuing	Potential in Nigeria

utritional implication	Sustainability	Future work	Priority (1 = high, 5 = low)
gh-quality forage, mproved carrying capacity, upplemental dry-season grazing	Process may not be sustainable for smallholder; competition with food crops	Ratooning varieties and interspecific hybrids, appropriate conservation needed	2–Global 2–SADCC
ow nutritive value requires mprovement and variety levelopment; supplementation salt and bran)	Process can be used in existing systems	Supplement with legume forage, browse by-products, and greater quantities of harvestable leaves	1–Global 1–SADCC
ow nutritive value under low nanagement to improve quantity f feed	Not sustainable in semi-arid tropics, only sustainable in high-rainfall areas	–	4–Global 5–SADCC
fects of tannin on protein positive effects in ruminants)	Economic value of bran important in milling industry and small-scale dehulling	Incorporate tannin brans in dairy cattle feed	1–Global 1–SADCC
nproved feed efficiency in eef feeds proved value for cattle feed	Realistic pricing for grains (sorghum, millets, and byproducts)	Alternative uses of sorghum and millets as feed instead of food	4–Global 4–SADCC
educed tannin products (end roduct); improved feed value	Unknown	–	4–Global 4–SADCC
nproved rate of grain and eed efficiency; low raction III protein; reduced ost of feed processing	Significant potential for improving animal production in SADCC region; important for poultry and swine	–	2–Global 2–SADCC
–	–	–	1-5–Global 1-5–SADCC

Discussion Spreadsheet – Feeds – Group IV

		Level of application	
Process	Product	Research	Research and development
1. High moisture harvest	Green forage/hay	Varieties with better quality, competition with food crops, reduced polyphenols, brown midrib	Mechanized farming of sweet sorghum
2. Harvest	Crop residue	Dual-purpose varieties, new varieties with higher energy, economic returns to harvest, storage	Smallholders and commercial enterprises
3. Ensiling	Silage	–	Low application for dairy farms, no application for smallholders, highly mechanized systems
4. Dehulling	Bran	Treating high-tannin brans with alkali, level of tannin bran in diets, milling yield, and nutritive value of bran	–
5. Milling of grain	Dry milled, rolled, fine ground, pellet	Small-scale feed processing, long-term market for grain-fed cattle, technology treansfer (only hammermill viable)	–
6. Steam flaking, rolling, conditioning, reconstituting, pressure cooking, popping, micronizing	Flakes, popped products, etc.	–	Technology already available
7. Alkali treatment and local villabe processing	High-tannin grain (raw material)	Mineral soils for tannin detoxification *Magadi* salts (Tanzania) Soda ash plant being built (Botswana)	–
8. Improving grain quality for feed	Whole grain	Technology (research) Potential benefits of breeding Breed low-tannin bird-resistant varieties Improve carotenoid pigments in sorghum and millet grain by breeding	–

Nutritional implications	Sustainability	Future work	Priority (1 = high, 5 = low)
High-quality forage, improved carrying capacity, supplemental dry-season grazing	Process may not be sustainable for smallholder; competition with food crops	Ratooning varieties and interspecific hybrids, appropriate conservation needed	2–Global 2–SADCC
Low nutritive value requires improvement and variety development; supplementation (salt and bran)	Process can be used in existing system	Supplement with legume forage, browse byproducts, and greater quantitites of harvestable leaves	1–Global 1–SADCC
Low nutritive value under low management to improve quantity of feed	Not sustainable in semi-arid tropics, only sustainable in high-rainfall areas	–	4–Global 5–SADCC
Effects of tannin on protein (positive effects in ruminants)	Economic value of bran important in milling industry and small-scale dehulling	Incorporate tannin brans in daily cattle feed	1–Global 1–SADCC
Improved feed efficiency in beef feeds	–	Alternative uses of sorghum and millets as feed instead of food	4–Global 4–SADCC
Improved value for cattle feed	Realistic pricing for grains (sorghum, millets, and byproducts)	–	4–Global 4–SADCC
Reduced tannin products (end product); improved feed value	Unknown	–	2–Global 2–SADCC
Improved rate of grain and feed efficiency Low fraction III protein Reduced cost of feed processing	Significant potential for improvinganimal production in SADCC region Important for poultry and swine		1–5–Global 1–5–SADCC

Primary Food Processing—Group I

Participants	Disciplines
M.I. Gomez, Group Leader	Food Technologist
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S. Dinat	Administrator
M.C. Kaumba	Economist
A. Moshe	Food Technologist
S.Z. Mukuru	Breeder
T. Rukini	Engineer
F.E. Sauwa	Manager
R.E. Schaffert	Breeder
V. Subramanian	Biochemist
R.B.H. Wills	Food Technologist

1. There is need to recognize and develop differential quality requirements of sorghum for traditional and commercial primary processing. For example, traditional dehulling preference is for thick pericarp and soft/intermediate endosperm grains, while commercial abrasive hulling/milling requires thin pericarp and vitreous grain. Processing research is needed to optimize traditional technologies with regard to the degree of conditioning for maximum milling yield, period of presoaking/pregermination, maximum removal of tannins, etc.

2. Several mechanical hulling/milling systems (such as modified wheat milling, abrasive dehulling, conditioning and impact, and semiwet milling) have been developed to the research and development and semi-industrial stage. Systematic comparative evaluation of hulling/milling performance of these systems (extraction rate, etc.), based on selected check varieties, is needed. Collaborative studies should be initiated.

3. Differential studies should be initiated on breeding/selection and processing systems for (a) porridge meal, and (b) baking flour and other milling fractions, such as semolina and grits.

4. Further research is needed on nutritional implications of traditional processing methods, notably acid/alkali treatments and possibilities of application on an industrial scale for treatment of sorghum grain as well as bran. This can be significant in extending the use of high-tannin brown sorghum grains for food.

5. Pearled sorghum rice analog has gone through research and development and has reached the test marketing stage in several countries (Sudan, Kenya, Botswana). Quality standards are still not optimized for color, grain size, texture, cooking quality, etc., in relation to appropriate varieties. Selection pressure is needed. Rice analog is an important commodity in SADCC countries that do not grow rice.

6. Malting is an important process, not only for production of opaque and clear beer but for food malts and weaning foods based on improved nutritional quality of malted grain. Grain selection in sorghum and millets for good malting quality is a high priority in the SADCC region, as well as in western and eastern Africa. Breeding and processing research need to be intensified for identifying grains with high diastatic units and high free amino nitrogen (for brewing malts), and those with moderate diastatic units and good flavor profile (for food malts).

7. ethodologies need to be standardized for quality evaluation, such as micromalting and diastatic activity determinations through interlaboratory trials on selected check varieties of sorghum and millets.

8. Research is needed to extend application of processing technologies, such as flaking and micronization, to human foods, and to optimize these processes for cost efficiency and nutritional and food quality.

9. Industrial processes such as extrusion cooking need to be explored as sources of pregelatinized sorghum flour and complementary cereal/legume precooked mixtures, such as *soyogi* in western Africa. Extrusion cooking capacity is now established in Botswana and Zimbabwe.

10. Chewing sorghums are widely consumed throughout the SADCC region, though their relative importance in diets is unknown. Industrial use of sweet sorghum for sugar and alcohol is not a high priority for the SADCC region, but where it is feasible (as in Brazil), selection for high sugar, low fiber, high extractability, and multiple ratooning is needed.

11. Introduction of high-lysine sorghums for milk, dough, and hard-stage consumption (as in Ethiopia) should be explored in the SADCC region. Acceptability should be tested, but not as a high priority.

12. Standardization of the physical, chemical, and functional quality testing methodologies (for grain hardness, tannin content, dough quality, and digestibility) through interlaboratory evaluations on a range of check varieties is needed.

13. There is a need to standardize terminologies regarding color descriptors and high and low tannin quantification.

Similarly, methods of measuring related qualitative descriptions should be standardized (for instance, hardness can be measured on an instrumental scale, a milling yield scale, or a particle size index scale). Implied in this is the need to identify a network of cooperating laboratories with resource capabilities in specific areas. A consensus was expressed that the SADCC/ICRISAT Sorghum and Millets Improvement Program should serve as a reference and coordinating center of such activity for the SADCC region.

Secondary Food Processing—Group II

Participants	**Disciplines**
L.W. Rooney, Group Leader	Agronomist/Chemist
J.S.T. Bogunjoko	Food Technologist
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J.C. Faure	Food Technologist
L. Majoko	Chemist
P. Matete	Nutritionist
M. Mudimbu	Technologist
J. Mwale	Food Technologist
N.F. Nicholson	Industrial Engineer
A.T. Obilana	Breeder
O. Olatunji	Food Technologist

1. Composite flour technology for production of a range of products (bread, cookies, biscuits, and pastas), incorporating sorghum and millet flour, has been developed in many countries, including SADCC countries such as Zimbabwe. In wheat-importing countries, sorghum- and millet-based composite products are a high priority. Selection of varieties that show good milling/baking/extrusion characteristics and favorable pricing policies is desirable.

2. Countries with little or no wheat production should direct breeding and processing research to nonwheat products such as bread and biscuits. But the feasibility of nonwheat products is low in most SADCC countries unless wheat is not available at all (as in Nigeria). This recommendation is therefore given low priority.

3. Thin and thick cereal porridges are consumed throughout Africa. Considerable research relating grain quality to porridge quality is already available. More work is needed on a pilot scale to develop a ready-to-cook sorghum and millet porridge meal. Organoleptic problems with millet flour need to be studied to determine if they can be solved by varietal improvement or by processing.

4. Research and development and semi-industrial scale studies in Nigeria and Mexico have demonstrated the feasibility of 100% replacement of barley malt with sorghum malt in clear beer. There should be selection pressure for identification of varieties with high diastatic units for this purpose. This application is a high priority in countries dependent on imported barley malt and enzymes. It is a high priority for the SADCC region generally, and a medium to low priority for Zimbabwe, which has export capacity for barley malt.

5. Opaque beer, based on sorghum malt, is a traditional product in eastern and southern Africa. It is already commercialized in southern Africa. The product is a high-priority item as both food and beverage, but the technology still needs to be optimized, especially with regard to organoleptic and nutritional quality. Screening of both sorghum and millet varieties for good malting, gelatinization, and organoleptic quality is needed to extend the technology in SADCC countries. Grain and product quality research on such processes as acid fermentation in fermented porridges, which are widely consumed in the SADCC region, needs attention.

6. Low bulk, nutritionally adequate weaning food is a high priority for the whole SADCC region. Some research has been initiated in the region, as in Tanzania, but more research and development is needed to develop practical, low-cost weaning food formulae that include malt as the bulk-reducing agent. Both traditional use and commercial application need to be encouraged.

Industrial Uses—Group III

Participants	Disciplines
L.R. House, Group Leader	Breeder
L. Hallgren	Food Technologist
O.A. Koleoso	Food Technologist
J. Moncada	Engineer
R.E. Schaffert	Breeder
C. Wenman	Engineer/Industry

1. **Sweet sorghum milling.** In many countries, there is a deficit of fuels and/or ethyl alcohol for industrial use. Technology has been developed for the extraction of the sugar from sweet sorghum biomass and for its transformation into alcohol. Depending on the demand and price of alcohol, this becomes a profitable enterprise with valuable byproducts: grain, bagasse, and stillage. The grain has the same value as any other grain and may be utilized as a food or feed. The bagasse and stillage may be transformed into biogas and biofertilizer in energy-deficient regions. In this transformation of bagasse to biogas, animals may be used by feeding them the bagasse and using the manure to fuel the biodigester. The biofertilizer should be returned to the soil to maintain fertility. Cultivar improvement should focus on maximum alcohol production and maximum biological value of the bagasse for animal forage.

2. **Sorghum crop residue for biogas production.** In many regions, there is a shortage of energy for domestic uses and, as in Botswana, a shortage of energy to pump water for animal use. Sorghum residue can be used as the biomass source in a biodigester for production of biogas. The technology for this process already exists. Sorghum can be improved to produce more carbohydrates in the stalks (residue) to improve the yield of this process (sweet stalk type). This should not reduce the potential of grain production.

3. **Dry milling of grain.** Industrial starch is important and is already well commercialized to make such products as adhesives, as a core binder for well drilling, and in ore refining. As there is good potential for such uses, breeders should select grains with good dry-milling characteristics. In Zimbabwe, for example, a demand exists for waxy starch. Existing waxy endosperm hybrids and varieties should therefore be evaluated for industrial use and, if promising, bred for high yield.

4. **Wet milling.** Sorghums with the potential for wet milling to produce starch should be developed as part of the improvement program. Potential for use of waxy sorghum exists in certain areas. Sorghums for wet milling would have intermediate texture, yellow and perhaps waxy endosperm. This is not, however, a high priority.

5. **Dry milling of straw.** The products are fuel pellets, particle and building boards, and cellulose pulp for the paper industry. Research has been conducted on cereals other than sorghum. No pilot research and no industrial/commercial application exists for sorghum straw.

Sorghum is known to produce an extremely high amount of biomass, and it could be an important renewable energy resource. Fuel pellets can be produced from a meal obtained by dry milling. This meal consists of leaves, nodes, and pith. Another product obtained by the mechanical separation is a fraction from internodes. This fraction is high in cellulose and lignin, and chips could be used in particle and building boards or as raw material for the paper pulp cellulose industry. All writing and printing paper produced in Denmark contains an average of 30% bleached wheat and rye straw cellulose. Sorghum straw could be explored as an alternative.

Research and development is needed to obtain raw materials which, during dry milling, produce optimal fractions for those three products. This can be done in a collaborative study with Carlsberg Research Laboratory, where laboratory equipment is available.

Feeds—Group IV

Participants	Disciplines
J.D. Reed, Group Leader	Animal Nutritionist
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J.D. Axtell	Breeder
S.C. Gupta	Breeder
R.C. Hoseney	Cereal Chemist
R. Jambunathan	Biochemist
F. Mmopi	Agronomist
D.S. Murty	Breeder
J.F. Mushonga	Breeder

1. The development of dual-purpose sorghum varieties with improved forage quality and low-tannin grain is a high priority.

2. Alternative methods of bird control should be studied. Bird bait systems, where small plots of sorghum are sown near roosts to divert birds from large-scale production plots, are working in Zimbabwe. These are combined with spraying very effectively.

3. Breeding and research efforts to improve digestibility of sorghum grain should receive support. The genetic variation in sorghum germplasm should also be assessed for heritable variation in Landry Moreaux Fraction III storage protein. Improved varieties should be developed.

4. For use as high-moisture green forage, breeding efforts should be directed to interspecific hybrids, such as *Sorghum bicolor* × *S. Sudanense* and *Pennisetum glaucum* × *P. purpureum*, to forage cultivars that ratoon, and to improving nutritive quality in preference to yield. However, forage potential for smallholder cut-and-carry systems may not be sustainable where there is competition with food crops.

5. Crop residue utilization, on the other hand, is highly applicable to existing small-scale and communal farming systems. The importance of crop residue as feed, fuel, construction material, and industrial raw material should be given high priority in crop improvement programs.

6. Dual-purpose varieties with greater nutritive value of the crop residue for ruminants should be developed.

7. The economic and ecological impact of the increased use of crop residues for feeding livestock in competition with other uses should be determined.

8. A high priority should be given to exploring sources of alkali salt for treatment of high-tannin sorghum grain and bran to improve the feed efficiency of these materials for ruminant and monogastric feeds, and to determining the nutritive value and levels of grain and bran that can be incorporated into feeds. The economic implications of the use of bran from tannin-containing sorghum should be determined for the use of these sorghum varieties by the milling industry.

9. The introduction of the brown midrib mutation and other genetic manipulations that reduce the effects of lignin on forage digestibility should be studied.

10. Further research on the positive effects of tannins in sorghum bran on protein utilization by ruminants—especially by dairy cattle—should receive priority in order to extend the feed value of high-tannin brans.

11. The pricing policy for sorghum and millets, as well as for other cereals, should be consistent with the biological and economic value of the crop.

12. Swine and poultry producers will be important consumers of sorghum and millets in the SADCC region, and crop improvement efforts should consider the use of grain in diets of simple stomach livestock in addition to cattle diets.

13. The use of sweet, juicy-stem varieties of sorghum in forage production systems should be considered. Consideration of sweet, juicy-stem types against nonsweet, dry-stem varieties may be useful.

14. Priority should be given to evaluating opportunity costs and returns to the use of sorghum and millet stover, grain, and bran for feeding draft animals before sowing to improve draft quality.

15. There is a need to explore opportunities and constraints relating to the use of feeds based on sorghum and millets, including forage and grain for fattening the cattle of small farmers for market sales, and to evaluate opportunities for stall or pen feeding strategies. This could form a potential basis for increasing small-farm incomes in the semi-arid zones.

16. Guidelines should be established for price and market adjustments necessary for stimulating greater use of sorghum and millet products in the formal and informal (farm-based) feed industry.