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Processing of Different Wheat Flour-Supplemented Sorghum Flakes (Sorghum and Wheat of Saudi Arabia): Sensory, Nutritional, and Microbiological Evaluation

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ABSTRACT

Sorghum-based flakes were produced alone and with 10 and 50% blends of different wheat flour (75% extraction rate). Sensory, chemical, nutritional, and microbiological evaluation of the flakes were investigated. Panellists (n = 20) rated the sensory characteristics and found no significant difference in overall acceptability between sorghum- and wheat-supplemented sorghum flakes. Wheat supplementation increased protein and total sugar contents but decreased fat, ash, and crude fibre. Mineral composition of the flakes generally showed an abundance in sodium, potassium, magnesium, phosphorus and iron but shortages in calcium and copper. However, the 50% wheat replacement resulted in higher iron but lower phosphorus and zinc contents. The 50% blend increased lysine, histidine, arginine, proline, and glutamic acid but decreased leucine and alanine. In general, Saudi No. 4 wheat flour-supplemented flakes had the best amino acid profile. Chemical scores for all samples were higher than those of most similar commercial breakfast cereals. However, lysine and methionine + cystine were still the limiting amino acids.

Total microbial counts, moulds and yeast counts, total coliforms, and spore-formers were very low or absent in all flakes.

INTRODUCTION

Sorghum is one of the old crops which originated in North Africa. Its cultivation spread to India, the Middle East, China and recently to America

(Kent, 1983). Sorghum is the staple diet in many developing countries in Asia, Africa, and central America. In the developed countries, it is mainly used for animal feed and the fermentation industry (Martin & MacMasters, 1951). Recently, sorghum cultivars have been used for the production of tortillas which are staple food for many people (Choto *et al.*, 1985; Serna-Saldivar *et al.*, 1988).

Sorghum varies in chemical composition due to varietal and seasonal differences (Neucere & Sumrell, 1980; Banda-Nyirenda *et al.*, 1987). Protein content in sorghum is comparable with that of wheat (Miller *et al.*, 1964; Virupaksha & Sastry, 1968). However, sorghum is deficient in lysine, tryptophan, and the sulphur-containing amino acids but is relatively high in leucine. Varietal differences exist for sorghum in amino acid profiles (Brener & Dohm, 1972; Neucere & Sumrell, 1979; Sikka & Johari, 1979). Desikachar (1975) and Neucere & Sumrell (1980) have reported the mineral composition of sorghum varieties.

Sorghum was once one of the major crops in Saudi Arabia but its use was limited to animal feed; the production declined by 73% in 1984/85 compared to that in 1981/82 (DESS, 1984/85). On the other hand, wheat production in Saudi Arabia has increased dramatically from 199 000 tons in 1981 to more than 2·54 million tons in 1986 (DESS, 1987). Wheat is a good food and may enhance nutritional intake. However, sorghums are more resistant to drought, pests and diseases and do well in semi-arid conditions. One way to promote sorghum cultivation and to reduce dependence on wheat is to find a wider use of the crop than animal feed. This can be achieved by incorporating sorghum into breakfast cereal types of product. Blending of cereal products or blending cereals with legumes has resulted in higher nutritional value of finished products (Sheheta & Freyer 1970; Choto *et al.*, 1985; Gayle *et al.*, 1986; Bookwalter *et al.*, 1987; Buck *et al.*, 1987; Sanchez-Marroquin *et al.*, 1987). Changing habits and life styles of Saudi society have increased the needs for these products because of convenience, high calorie and nutrition value, low fat, and better keeping quality. Flaked products are usually consumed with milk and together they should approximate to a good meal not only for breakfast but also at other times. There have not been any attempts to utilize the locally-produced sorghum or wheat in the manufacture of flaked products or any other type of ready-to-eat breakfast cereals and this might be due mainly to lack of research in this area. Therefore, this study was made to develop sorghum flakes and wheat-fortified sorghum flakes. The effects of wheat flour supplementation to sorghum flour on consumer acceptance, chemical and mineral composition, and amino acid and chemical scores were evaluated. Microbial studies were conducted on all finished products.

MATERIALS AND METHODS

Materials

Sorghum (*Sorghum bicolor* {local}, caudatum) was obtained from a farm in the southern region of Saudi Arabia and was milled to pass a 0·25 mm sieve with Ultra-centrifugal mill, Resh type ZM1, No. 140. Wheat samples were obtained from the Grain Silos and Flour Mills Organization in Riyadh, Saudi Arabia. The classification to Saudi No. 1, Saudi No. 2, Saudi No. 3, and Saudi No. 4 was made by the organization. The grade classifications were based on approximate protein range (%), weight (hectolitre, kg/hl), and impurities (%) as follows: ≥12·5, ≥75, <3·5 for No. 1; 10–12·4, 69–<75, 4–12 for No. 2; 7–<10, <69, <12, for No. 3, respectively. Dark-tip wheat kernels (>35%) were graded No. 4 regardless of protein content. The moisture content must not exceed 12% for all grades. Wheat samples were then ground with a Quadrumat Senier Auto-Mill to obtain 75% extraction rate.

Processing

The experiment consisted of ten groups of treatments and the control (sorghum flour {SF}). Wheat flour of; Saudi No. 1(WFS1), Saudi No.2(WFS2), Saudi No. 3(WFS3), Saudi No. 4(WFS4); and durum flour (DF) were individually blended (dry) with sorghum flour so that 10% and 50% by weight of the sorghum flour were replaced by wheat flour. Many preliminary experiments had been conducted to obtain the optimum formulation and processing conditions for the production of flaked-type product. The flowchart shown in Fig. 1 represents the procedure used to make sorghum flakes and wheat-fortified sorghum flakes.

Sensory evaluation

Colour, taste, texture, aroma, and overall acceptability of sorghum flakes and wheat flour-fortified sorghum flakes were subjectively determined by 20 untrained panellists (students and technicians of Food Science Department) using a 9-point scale (Fig. 2). Analyses were performed in well-equipped sensory evaluation booths. Drinking water was available for rinsing the mouth between samples. Sensory data were analyzed using Duncan New Multiple Range Test (Steel & Torrie, 1980) and SAS computer programs.

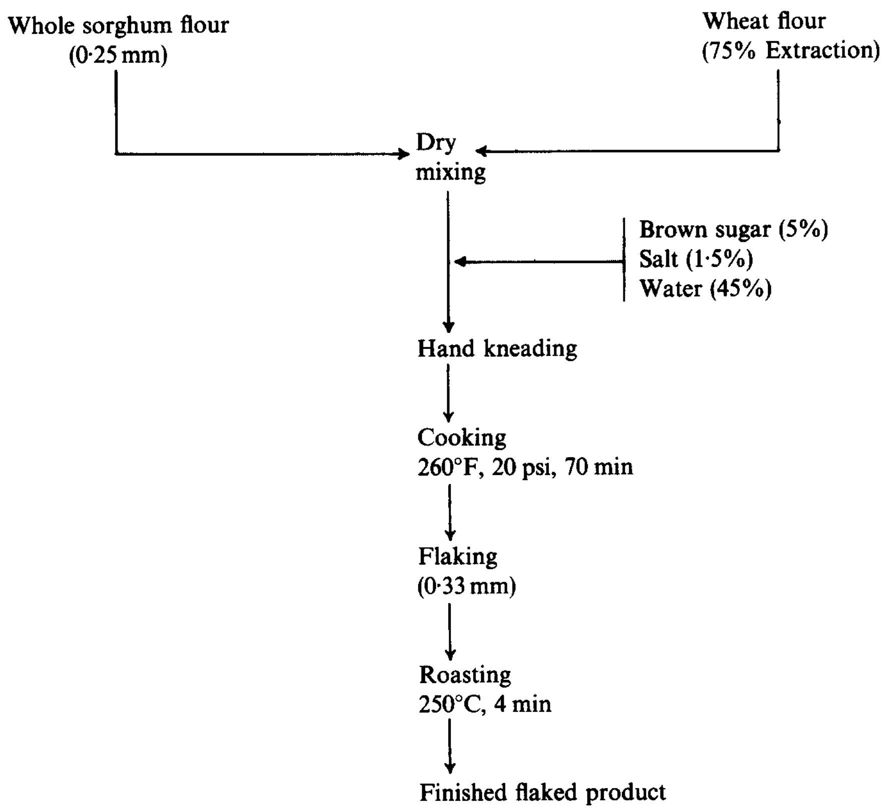

Fig. 1. Steps for making sorghum flakes and wheat flour-fortified sorghum flakes.

Chemical determinations

Proximate analyses, for moisture, protein, fat, crude fibre, ash, reducing sugars and total sugars, were conducted according to AOAC (1980). Carbohydrates were calculated by difference. Sodium, potassium, calcium, magnesium, iron, zinc, manganese and copper were determined by an atomic absorption spectrophotometer (1100 B Perkin-Elmer) after wet ashing (AOAC, 1980). Phosphorus was determined spectrophotometrically using a modified molybdenum blue method recently reported by Abu-Lehia (1987).

Samples of ground flakes were hydrolyzed with 6N HCl for 24 h at 110°C according to the LKB manual (1983). The amino acids were analyzed with a LKB Model 4150 ALPHA amino acid analyzer. The chemical score was calculated by dividing the contents of the essential amino acids in sorghum flakes and wheat flour-fortified sorghum flakes by their amounts in FAO/WHO reference protein (FAO/WHO, 1973; Sanchez-Marroquin *et al.*, 1987). At the present time, a protein efficiency ratio (PER) study cannot be

Name:
Date:
Sample Code:

Colour	Dark			Gold			Light		
	1	2	3	4	5	6	7	8	9
Taste	Not enough			Desirable			Strong		
	1	2	3	4	5	6	7	8	9
Texture	Too hard			Hard			Crispy		
	1	2	3	4	5	6	7	8	9
Aroma	No aroma			Pleasant			Strong		
	1	2	3	4	5	6	7	8	9
Overall acceptability	Unacceptable			Acceptable			Excellent		
	1	2	3	4	5	6	7	8	9

Comments:

Fig. 2. Sensory evaluation questionnaire for sorghum flakes and wheat flour-fortified sorghum flakes.

done because of the unavailability of rats and stainless steel wire cages. However, PER, true digestibility, biological value and net protein utilization of the flaked products will be determined as soon as rats are available and the results will be separately published.

Microbiological assays

The total microbial count including bacteria, yeast, and moulds was conducted by using the total plate count agar (PCA) procedure as described by Banwart (1979). The plates were incubated at 32°C for 2 days and the results were reported as the aerobic plate count per gram of sample. Acidified (10% tartaric acid) potato dextrose agar medium was applied for yeast and mould counts. The plates were incubated at 25°C for 5 days and the results were reported as yeast and mould colonies per gram of sample (Busta *et al.*, 1984). Violet red bile (VRB) agar was used to detect the presence of total coliform after incubation at 37°C for 24 h (Mehlman, 1984). Spore-formers were investigated by plating samples with PCA media after heating at 80°C for 10 min.

RESULTS AND DISCUSSION

Sensory evaluation

The sensory means for sorghum flakes prepared with 10 and 50% wheat flour are given in Tables 1 and 2. The colour was significantly improved by the addition of 10% WFS_1 but was inferior when 10% DF was added. Panellists rated the aroma and the taste of 50% WFS_1 and 50% WFS_2 flakes, respectively, lower than the control sample. However, the overall acceptability, of all wheat-fortified sorghum flakes was not significantly ($P > 0{\cdot}05$) different from those of sorghum flakes at any level of substitution. The finished flakes were generally characterized by relatively hard texture, gold-brown colour, and desirable taste. The sensory characteristics of the

TABLE 1
Sensory Characteristics of Sorghum Flakes Made with 10% Wheat Flour of Different Type

Sample[a]	*Sensory parameters*[b]				
	Colour	*Texture*	*Aroma*	*Taste*	*Overall acceptability*
SF	$5{\cdot}45 \pm 1{\cdot}73^{bc}$	$5{\cdot}25 \pm 2{\cdot}00^{a}$	$4{\cdot}05 \pm 1{\cdot}79^{a}$	$4{\cdot}55 \pm 1{\cdot}82^{a}$	$5{\cdot}10 \pm 1{\cdot}52^{a}$
90SF:10WFS_1	$6{\cdot}15 \pm 2{\cdot}13^{a}$	$5{\cdot}55 \pm 2{\cdot}04^{a}$	$4{\cdot}20 \pm 1{\cdot}79^{a}$	$4{\cdot}90 \pm 1{\cdot}59^{a}$	$5{\cdot}45 \pm 1{\cdot}91^{a}$
90SF:10WFS_2	$4{\cdot}95 \pm 1{\cdot}57^{cd}$	$5{\cdot}50 \pm 1{\cdot}82^{a}$	$3{\cdot}85 \pm 1{\cdot}87^{a}$	$4{\cdot}80 \pm 1{\cdot}99^{a}$	$5{\cdot}15 \pm 1{\cdot}53^{a}$
90SF:10WFS_3	$5{\cdot}90 \pm 1{\cdot}68^{ab}$	$5{\cdot}90 \pm 1{\cdot}45^{a}$	$3{\cdot}90 \pm 1{\cdot}89^{a}$	$5{\cdot}20 \pm 1{\cdot}64^{a}$	$5{\cdot}35 \pm 1{\cdot}42^{a}$
90SF:10WFS_4	$5{\cdot}15 \pm 1{\cdot}53^{c}$	$5{\cdot}70 \pm 1{\cdot}95^{a}$	$3{\cdot}70 \pm 1{\cdot}98^{a}$	$4{\cdot}65 \pm 1{\cdot}49^{a}$	$4{\cdot}90 \pm 1{\cdot}21^{a}$
90SF:10DF	$4{\cdot}10 \pm 1{\cdot}86^{d}$	$5{\cdot}55 \pm 1{\cdot}90^{a}$	$3{\cdot}70 \pm 2{\cdot}05^{a}$	$4{\cdot}80 \pm 2{\cdot}42^{a}$	$5{\cdot}05 \pm 1{\cdot}85^{a}$

[a] SF = Sorghum flour; WFS_1 = Wheat flour of Saudi No. 1; WFS_2 = Wheat flour of Saudi No. 2; WFS_3 = Wheat flour of Saudi No. 3; WFS_4 = Wheat flour of Saudi No. 4; DF = Durum flour.
[b] Means in a column with the same letter are not significantly different from each other ($P > 0{\cdot}05$).

TABLE 2
Sensory Characteristics of Sorghum Flakes Made with 50% Wheat Flour of Different Type

Sample[a]	*Sensory parameters*[b]				
	Colour	*Texture*	*Aroma*	*Taste*	*Overall acceptability*
SF	$6{\cdot}40 \pm 2{\cdot}01^{a}$	$4{\cdot}75 \pm 2{\cdot}07^{a}$	$4{\cdot}10 \pm 2{\cdot}67^{ab}$	$5{\cdot}15 \pm 2{\cdot}16^{a}$	$4{\cdot}35 \pm 2{\cdot}03^{a}$
50SF:50WFS$_1$	$6{\cdot}30 \pm 2{\cdot}05^{ab}$	$4{\cdot}10 \pm 1{\cdot}45^{a}$	$3{\cdot}05 \pm 1{\cdot}93^{b}$	$4{\cdot}65 \pm 1{\cdot}35^{ab}$	$5{\cdot}15 \pm 1{\cdot}49^{a}$
50SF:50WFS$_2$	$5{\cdot}25 \pm 1{\cdot}80^{bc}$	$4{\cdot}25 \pm 1{\cdot}77^{a}$	$3{\cdot}75 \pm 1{\cdot}94^{ab}$	$3{\cdot}95 \pm 1{\cdot}70^{b}$	$5{\cdot}10 \pm 2{\cdot}07^{a}$
50SF:50WFS$_3$	$4{\cdot}65 \pm 1{\cdot}81^{c}$	$4{\cdot}80 \pm 1{\cdot}88^{a}$	$3{\cdot}95 \pm 2{\cdot}09^{ab}$	$4{\cdot}90 \pm 1{\cdot}94^{ab}$	$5{\cdot}15 \pm 1{\cdot}57^{a}$
50SF:50WSF$_4$	$5{\cdot}30 \pm 1{\cdot}81^{bc}$	$5{\cdot}15 \pm 2{\cdot}48^{a}$	$4{\cdot}30 \pm 2{\cdot}20^{a}$	$5{\cdot}25 \pm 1{\cdot}97^{a}$	$5{\cdot}25 \pm 1{\cdot}62^{a}$
50SF:50DF	$5{\cdot}75 \pm 1{\cdot}68^{ab}$	$5{\cdot}00 \pm 1{\cdot}84^{a}$	$3{\cdot}90 \pm 2{\cdot}40^{ab}$	$4{\cdot}65 \pm 2{\cdot}41^{ab}$	$4{\cdot}30 \pm 1{\cdot}49^{a}$

[a] SF = Sorghum flour; WFS$_1$ = Wheat flour of Saudi No. 1; WFS$_2$ = Wheat flour of Saudi No. 2; WFS$_3$ = Wheat flour of Saudi No. 3; WFS$_4$ = Wheat of Saudi No. 4; DF = Durum flour.
[b] Means in a column with the same letter are not significantly different from each other ($P > 0{\cdot}05$).

finished flakes are the results of reactions such as dextrinization, gelatinization, caramelization, and Maillard reactions which usually take place during processing of breakfast cereals (Kent, 1983). The flakes produced in this study had no other ingredients beside sorghum flour, wheat flour, brown sugar, salt, and water. Their sensory characteristics could have been even better if other ingredients had been added.

Chemical composition

Table 3 shows the proximate composition of sorghum flakes and wheat-fortified sorghum flakes. Wheat supplementation resulted in an increase in protein and total sugar but in a decrease in fat, ash, and crude fibre. The highest protein contribution was given by 50% DF and 50% WFS$_1$ supplementation while the highest sugar contents were found in 50% WFS$_2$-supplemented flakes. The decrease of crude fibre and ash with increasing wheat substitution might be due to the use of 75% extraction wheat flour which was found by Zeleny (1971) to contain only 0·45–0·5% ash. The differences in carbohydrates and calorie values among samples were small. Literature searches did not reveal data on sorghum flakes since flaked products are usually made from wheat, maize, or rice. The chemical compositions of commercial ready-to-eat breakfast cereals vary widely, depending on formulations and ingredients chosen by the processor. Fincken Ltd. (1982) reported 3·8, 10·6, 3·4, 2·2, 8·0, 8·0 and 78·8% for

TABLE 3
Proximate Composition[a] of Sorghum Flakes and Wheat Flour-Fortified Sorghum Flakes (g/100 g dry matter)

Sample[b]	*Moisture*	*Protein* ($N \times 5\cdot7$)	*Fat*	*Crude fibre*	*Ash*	*Reducing sugar*	*Total sugar*	*Carbo-hydrates*[c]	*Caloric value (kcal/100 g)*
SF	3·60 ± 0·16	8·94 ± 0·07	1·57 ± 0·14	2·89 ± 0·11	3·13 ± 0·09	3·11 ± 0·20	4·67 ± 0·31	83·51	382
90SF:10WFS$_1$	3·66 ± 0·20	9·18 ± 0·11	1·42 ± 0·13	2·81 ± 0·29	3·11 ± 0·32	3·37 ± 0·27	5·18 ± 0·46	83·48	383
50SF:50WFS$_1$	4·95 ± 0·17	11·01 ± 0·64	0·82 ± 0·18	2·45 ± 0·81	2·39 ± 0·33	5·31 ± 0·73	8·95 ± 0·85	83·33	372
90SF:10WFS$_2$	4·63 ± 0·26	9·26 ± 0·10	1·59 ± 0·61	2·65 ± 0·22	3·13 ± 0·07	3·40 ± 0·31	6·55 ± 1·51	83·56	384
50SF:50WFS$_2$	4·65 ± 0·37	10·59 ± 0·77	0·88 ± 0·14	2·40 ± 0·59	2·81 ± 0·09	6·81 ± 0·15	11·53 ± 0·87	83·32	383
90SF:10WFS$_3$	3·79 ± 0·18	9·18 ± 0·09	1·47 ± 0·14	2·75 ± 0·29	3·05 ± 0·23	3·00 ± 0·67	6·23 ± 1·39	83·55	384
50SF:50WFS$_3$	3·82 ± 0·29	9·09 ± 0·83	0·86 ± 0·21	2·38 ± 0·38	2·59 ± 0·13	2·07 ± 0·10	9·35 ± 0·59	85·08	384
90SF:10WFS$_4$	3·90 ± 0·01	9·24 ± 0·14	1·43 ± 0·19	2·71 ± 0·13	3·00 ± 0·02	3·32 ± 1·01	6·24 ± 0·98	83·62	384
50SF:50WFS$_4$	3·19 ± 0·48	9·92 ± 0·38	0·70 ± 0·43	2·64 ± 0·91	2·56 ± 0·46	4·13 ± 0·14	5·16 ± 0·21	84·18	377
90SF:10DF	3·65 ± 0·08	9·29 ± 0·07	1·48 ± 0·70	2·76 ± 0·41	3·07 ± 0·05	2·36 ± 0·73	6·74 ± 1·71	83·40	383
50SF:50DF	5·03 ± 0·31	11·98 ± 0·92	0·87 ± 0·18	2·58 ± 0·08	2·52 ± 0·14	4·21 ± 0·89	5·26 ± 0·66	82·05	383

[a] Mean of three determinations.
[b] Same as samples illustrated in Tables 1 and 2.
[c] Calculated by difference.

moisture, protein, fat, ash, dietary fibre, sugars and carbohydrates, respectively, and 1507 kJ in Force Wheat Flakes. Corn Flakes contained 3·0, 8·0, 0·3, 3·2, 2·0, 7·4 and 83·5%, and 1455 kJ in the same order (Kellogg Company, 1982). With the exception of dietary fiber the data (Table 3) on the produced flakes in this study are comparable to those for the commercial Force Wheat Flakes and Corn Flakes. Meredith & Caster (1984) determined the protein content in eleven commercial breakfast cereals and found the highest to be 20·18% for Special K and the lowest to be 4·81% for Kellogg's Sugar Frosted Flakes.

Mineral composition

The mineral concentrations of sorghum flakes and wheat-fortified sorghum flakes are shown in Table 4. Sodium, potassium, phosphorus and magnesium were in abundance while calcium was in shortage. Unlike zinc, iron was substantially increased by the 50% supplementation of the four Saudi wheat grades. Literature is lacking on sorghum flake mineral compositions. Popular ready-to-eat breakfast cereals, excluding bran products, which are commercially manufactured by Nabisco, Kelloggs, Quaker Oats, and Weetabix contained (mg/100 g) ranges of 10–1000 sodium, 58–403 potassium, 3–48 calcium, 3·5–6·7 (enriched to this level) iron, and 28–328 phosphorus (Kent, 1983).

The flakes produced in this study contained very good quantities of minerals, especially iron, when compared with the commercial products even though more refined wheat flour (75% extraction rate) was used (McCance *et al.*, 1945). Wheats grown in Saudi Arabia might differ from those grown in other countries and mineral concentrations in wheat flour are usually related to variety, level of fertility, and the environmental conditions under which the wheat was grown.

Amino acid composition

The contents of essential and non-essential amino acids in sorghum flakes and wheat-fortified sorghum flakes are shown in Table 5. Tryptophan was not determined. The concentrations of lysine, histidine, arginine, proline, and glutamic acid in the blends, particularly in the 50% blend, were higher than those of control (sorghum flakes). Wheat flour of Saudi No. 1 was the highest contributor of lysine at 50% supplementation level while Saudi No. 4 increased the contents of the other four amino acids at the same level of supplementation. The wheat of Saudi No. 4 was not given a lower grade by the Grain Silo and Flour Mill Organization because of its protein content but only because of its dark-tip kernels. Therefore, it is not surprising if

TABLE 4

Mineral Composition[a] of Sorghum Flakes and Wheat Flour-Fortified Sorghum Flakes (mg/100 g wet matter)

Minerals	*Sorghum flakes*	*Wheat—substituted flakes*									
		Durum		*Saudi No. 1*		*Saudi No 2*		*Saudi No. 3*		*Saudi No. 4*	
		10%	*50%*	*10%*	*50%*	*10%*	*50%*	*10%*	*50%*	*10%*	*50%*
Sodium	408	401	414	405	413	407	397	402	398	430	452
Potassium	301	315	380	300	295	300	280	290	270	300	315
Calcium	6·70	7·3	8	6·3	6	6·5	7	6·7	6	6·8	8
Magnesium	89·7	96·4	123·8	87·5	95·3	89·4	91·8	87·5	80·3	89·4	85·2
Phosphorus	286	302	276	277	217	310	271	345	265	246	184
Iron	3	2·9	3·6	3	6·2	4	9·7	3·5	6·2	4	8·36
Zinc	5·5	5	4·8	3·2	2·1	3·4	2·0	3·4	2·5	2·4	1·9
Copper	—[b]	—	—	—	—	—	—	—	—	—	—
Manganese	2·7	2·6	2·7	2·5	1·9	2·1	2·3	2·7	2·8	2·6	2·9

[a] Mean of two determinations.
[b] Trace.

Saudi No. 4-supplemented flakes had a better amino acid profile (Table 5).

The levels of leucine were lower in wheat-fortified flakes and this was expected since sorghum is known to be higher in leucine than wheat. The sulfur-containing amino acids contents did not increase as expected in wheat-fortified flakes since these components are higher in wheat than sorghum (Kailasapathy *et al.*, 1985; Banda-Nyirenda *et al.*, 1987). The severe heat-treatment during processing might have transformed the sulfur-containing amino acids into oxidized forms such as methionine sulfoxide and cysteic acid (Satterlee & Chang, 1982). Meredith & Caster (1984) reported the amino acid concentrations (g/100 g) in selected breakfast cereals and found histidine 3·66, 3·22; isoleucine 3·48, 4·30; leucine 14·46, 17·44; lysine 0·83, 0·95; methionine 1·60, 2·39; phenylalanine 6·05, 6·98; threonine 3·05, 3·39; tyrosine 4·40, 5·18; and valine 4·60, 5·2 for Kellogg's Corn Flakes and Kellogg's Sugar Frosted Flakes, respectively. The comparison was made with these products because of unavailability of information on sorghum flakes in the scientific literature. The lysine loss is too prominent in cereal-based mixture and breakfast cereals during processing (Bjorck *et al.*, 1984; McAuley *et al.*, 1987). Dextrinization of starch to reducing sugar during toasting and prolonged heat-treatment during cooking can affect lysine and its reaction with the reducing constituents (El-Mahdy, 1974; Racicot *et al.*, 1981; Youssef *et al.*, 1986). The latter authors reported a decrease in some essential amino acids, especially phenylalanine, cystine, methionine and tryptophan during heat-processing. In this study, cooking at 260°F and 20 psi for 70 min, and roasting at 250°C for 4 min were severe enough to cause losses in amino acids, mainly lysine and sulfur-containing amino acids.

Protein scores

Table 6 shows the chemical scores of sorghum flakes and wheat-fortified sorghum flakes. Protein quality was evaluated in terms of chemical score. Lysine and methionine + cystine were the limiting amino acids and the deficiency for children was more severe than for adults when comparison was made to FAO/WHO reference patterns for children and adults (Sanchez-Marroquin *et al.*, 1987). This is of importance since children are the prime consumers of flaked products. The 50% supplementation of durum, Saudi No. 1 and Saudi No. 2 raised the chemical scores of lysine; thus, lysine became interchangably second to methionine + cystine. Meredith & Caster (1984) found that the chemical scores for lysine in Kellogg's Corn Flakes and Kellogg's Sugar Frosted Flakes were 11 and 12, respectively. The chemical scores of 11–45 were found by the authors for eleven selected breakfast cereals. The authors also found methionine to be the limiting amino acid

TABLE 5
Amino Acid Composition[a] of Sorghum Flakes and Wheat Flour-fortified Sorghum Flakes (g/16 g N)

Amino acid	*Sorghum flakes*	*Wheat—substituted flakes*									
		Durum		*Saudi No. 1*		*Saudi No. 2*		*Saudi No. 3*		*Saudi No. 4*	
		10%	*50%*	*10%*	*50%*	*10%*	*50%*	*10%*	*50%*	*10%*	*50%*
Isoleucine	2·90	3·11	2·88	2·80	3·13	2·32	3·33	2·39	3·10	2·12	4·43
Leucine	11·23	11·03	6·73	9·92	7·49	8·76	8·04	8·91	8·32	8·11	8·01
Lysine	1·0	0·97	1·59	1·19	1·95	1·01	1·70	0·72	1·54	0·63	1·84
Methionine	1·66	1·84	1·62	1·63	1·41	1·30	1·57	1·34	1·52	1·36	2·19
Phenylalanine	4·36	4·68	3·37	4·01	4·32	3·74	4·40	3·55	4·86	3·27	5·39
Threonine	2·36	2·28	1·73	2·07	1·95	1·99	1·91	1·89	2·11	1·69	2·66
Valine	3·91	4·29	3·33	3·88	3·65	3·27	4·07	3·30	4·12	3·10	5·04
Histidine	1·83	2·18	1·99	1·77	2·23	1·61	2·27	1·56	2·36	1·47	2·59
Aspartic acid	6·54	7·04	4·72	5·99	5·52	5·54	6·08	5·36	6·28	5·23	6·53
Serine	3·10	2·88	2·45	2·69	2·62	2·64	2·48	2·47	2·56	2·10	3·50
Glutamic acid	19·50	21·96	25·43	19·76	29·19	17·45	29·39	17·54	30·19	15·87	35·22
Proline	5·94	6·34	12·23	5·96	11·94	5·77	12·62	5·64	13·02	5·54	12·60
Glycine	2·57	2·80	2·24	2·47	2·75	2·28	2·83	2·29	3·01	1·99	3·63
Alanine	7·57	7·28	3·63	6·39	3·96	5·85	4·37	5·90	4·62	5·10	5·74
Cystine	0·12	0·04	—	0·04	—	0·05	—	0·11	0·27	0·10	0·87
Tyrosine	2·41	2·60	1·84	2·11	2·63	1·98	2·19	1·80	2·85	1·57	3·77
Arginine	2·69	2·58	3·10	2·55	3·33	2·34	3·77	2·48	3·81	1·97	4·41

[a] Mean of two determinations.

TABLE 6
Chemical Scores[a] of Sorghum Flakes and Wheat Flour-Fortified Sorghum Flakes

Amino acid	*Sorghum flakes*	*Wheat—substituted flakes*									
		Durum		*Saudi No. 1*		*Saudi No. 2*		*Saudi No. 3*		*Saudi No. 4*	
		10%	*50%*	*10%*	*50%*	*10%*	*50%*	*10%*	*50%*	*10%*	*50%*
Lysine	18[b]	18[b]	29	22[b]	36	18[b]	31	13[b]	28[b]	11[b]	33[b]
	41[b]	40[b]	66	50	81	42	71	30[b]	64	26[b]	77[b]
Methionine +	30	31	27[b]	28	24[b]	23	26[b]	24	30	24	51
Cystine	51	54	46[b]	48[b]	40[b]	39[b]	49[b]	41	51[b]	42	87
Threonine	59	57	43	52	49	50	48	47	53	42	67
	169	163	123	148	139	142	136	135	151	121	190
Leucine	160	158	96	142	107	125	115	127	119	116	114
	624	613	374	551	416	487	447	495	462	451	445
Isoleucine	73	78	72	70	78	58	83	60	78	53	111
	145	156	144	140	157	116	167	120	155	106	222
Valine	78	86	67	78	73	65	81	66	82	62	101
	196	215	167	194	183	164	204	165	206	155	252
Phenylalanine +	71	76	54	64	72	60	69	56	80	51	95
Tyrosine	111	121	87	102	116	95	110	89	129	81	153
Tryptophan	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

[a] For each amino acid, the data in the first row are based on FAO/WHO (1973) reference pattern for children (lysine = 5·5; Meth. + Cys. = 6·0; Leucine = 7·0; Isoleucine = 4·0; Valine 9·6; Phe. + Tyr. = 9·6; Tryptophan = 1·0). The data in the second row are based on FAO/WHO (1973) reference pattern for adults (Lysine = 2·4; Meth. + Cys. = 3·5; Threonine = 1·4; Leucine = 1·8; Isoleucine = 2·0; Valine = 2·0; Phe. + Tyr. = 6·0; Tryptophan = 0·7) (Sanchez-Marroquin *et al.*, 1987).
[b] First limiting amino acid.

(chemical score of 34) in Apple Jacks. However, they calculated the chemical score according to the method of Sheffner (1967).

The determination of protein efficiency ratio (PER) could not be done because of the unavailability of rats. Sorghum proteins were less digestible than those of other cereals (Kurien *et al.*, 1960; Daniel *et al.*, 1966) and the protein digestibility by rat was different from the digestibility by children (Maclean *et al.*, 1981). However, supplementation with wheat in this study did not provide substantial increase in protein quantity and quality and lysine remained the first or the second limiting amino acid. Supplementation of cereals with legumes has resulted in very good nutritional enhancement (Kailasapathy *et al.*, 1985; Gayle *et al.*, 1986; Bookwalter *et al.*, 1987).

Microbiological evaluation

The total plate counts, and mould and yeast counts were very low even in the lowest dilution of 1:10 and, in some samples, the counts were found to be nil. Therefore, the total microbial counts, and mould and yeast counts were considered to be <10 estimated aerobic plate count per gram and <10 estimated colonies per gram of sample, respectively (Busta *et al.*, 1984). Total coliforms were not found and spore-formers were only present in sorghum flakes and durum-fortified flakes in the range of 2–6 spores per gram in the lowest dilution of 1:10.

The sources of microflora in the flakes were mainly sorghum and wheat flours which were products or by-products of the grains. Christensen & Sauer (1982) indicated that the grains were contaminated with microflora (bacteria, protozoa, slime moulds, yeasts, and filamentous fungi) which occurred naturally with the growing plants, soil, and water. Flakes were investigated for the presence of total coliforms and spore formers since some of these might have survived heat-treatments during processing of the flakes. Spores of Bacillus, coliform bacteria, and several other genera are usually present in cereal flour (Banwart, 1979).

Microflora are of minor significance in processed and dried products such as breakfast cereals. The produced flakes prepared in this study were subjected to severe heat-treatments during cooking and roasting; furthermore, the low moisture in the finished flakes can guarantee good storage stability.

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