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Effect of Home and Industrial Processing on Protein Quality of Baby Foods and Breakfast Cereals

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The effect of home and industrial processing on the protein quality of baby foods and breakfast cereals, commonly consumed in Pakistan, was studied. The nutritive value of baby foods and breakfast cereals was determined chemically (including amino acid analyses) and biologically in N-balance experiments with growing rats. Lysine and threonine were found to be the limiting amino acids in home and industrially produced baby foods whereas lysine was the limiting amino acid in all the breakfast cereals. The lysine contents of home-prepared baby foods were damaged to a great extent at 150–160°C compared with 100–110°C. The levels of lysine (35–76%) and arginine (10–41%) were in all the breakfast cereals reduced by the industrial processing. The net protein utilisation (NPU) of home-prepared baby foods ranged from 51–81% as compared to 57–60% for industrially produced baby foods. The net dietary protein calorie per cent (NDp cal%) of home and industrially produced baby foods varied between 2.6 and 7.3% and between 7.0 and 7.1% respectively. The industrial processing reduced significantly the true digestibility (4–20%), biological value (13–34%) and net protein utilisation (17–41%) of all the breakfast cereals.

1. Introduction

Processing at home or industrial level may have a deleterious effect on the protein quality of food products as heat damage to protein can result from several types of reactions. The most severe form of damage is destruction by the transformation of protein nitrogen to other forms. However, less destructive reactions that render protein biologically unavailable are more common. Early work was chiefly devoted to the lysine reaction.[1] This reaction can take place at relatively low temperature, therefore lysine is regarded as the most heat-sensitive amino acid.[2] It would thus appear that any beneficial effect due to heat treatment might be reversed and result in damage. Thus food products such as baby foods and breakfast cereals, exposed to severe heat treatments, may have reduced protein quality.

Eggum[3] showed that commercially produced baby foods can have net protein utilisation values below 50%. In a further work it was shown that the low values were primarily due to processing.[4] The same observation was made by Abrahamsson and Hambraeus[5] with instant blends for infants and children.

Breakfast cereals are subjected to a variety of treatments ranging from simple drying to puffing by explosion. Caster and Parthemos[6] showed that most of the common breakfast cereals were unable to support growth in young rats. Available lysine in these products indicated that the Maillard reaction had taken place to a great extent during industrial preparation.[7] The protein efficiency ratio varied from −2.5 for puffed wheat, to +1.7 for quick oats[8] and in N-balance trials with rats

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very low values for net protein utilisation in breakfast cereals were obtained.[9] The present work was undertaken to investigate the effect of home and industrial processing on the protein quality of these products as consumed in Pakistan.

2. Experimental

2.1. Animal and diets

The experimental procedure has been described by Eggum.[10] Groups of five Wistar male rats each weighing approximately 75 g were used. The preliminary period lasted for 4 days and the balance period for 5 days. The rats were weighed at the beginning of the experiments and divided into groups of five such that the average weights of the groups differed by no more than ± 0.5 g. Weighing was repeated at the end of the preliminary and balance periods: access to feed and water was prevented 3 h before weighing. Each animal received 150 mg N and 10 g dry matter daily throughout the preliminary and balance periods. The N content of the diet was adjusted using a basal diet consisting of a N-free mixture (Table 1).

Table 1. Composition (parts by weight) of the nitrogen-free mixture

Potato starch (autoclaved)	767
Sucrose	90
Cellulose powder	52
Soya-bean oil	52
Mineral mixture[a]	40
Vitamin mixture[b] (mixed with autoclaved potato starch)	20

[a] To provide per kg diet: $CaCO_3$, 2.74 g; calcium citrate, $Ca_3C_{12}H_{10}O_{14}\cdot 4H_2O$, 12.33 g; $CaHPO_4\cdot 2H_2O$, 4.51 g; K_2HPO_4, 8.75 g; KCl, 4.99 g; NaCl, 3.08 g; $MgSO_4$, 1.53 g; $MgCO_3$, 1.41 g; ammonium ferric citrate (20.5–22.5% Fe), 0.61 g; $MnSO_4\cdot H_2O$, 8.0 mg; $CuSO_4\cdot 5H_2O$, 3.1 mg; KI, 1.6 mg; NaF, 20.3 mg; $AlNH_4(SO_4)_2\cdot 12H_2O$, 3.6 mg.

[b] To provide per kg diet: retinol equivalent, 1.2 mg; cholecalciferol, 7.4 μg; thiamin, 0.8 mg; riboflavin, 2 mg; nicotinamide, 8 mg; pantothenic acid, 2 mg; α-tocopherol, 0.4 mg; pyridoxine, 0.2 mg.

The baby foods commonly consumed in Pakistan were prepared according to traditional methods and cooking practices. Two commercial baby foods, Farex and Delhya (wheat porridge), were selected for comparison. The composition and the processing conditions of home-prepared baby foods are given in Table 2. The samples were freeze-dried before feeding.

Four industrially produced breakfast cereals vermicelli, cornflakes, puffed corn and rice krunchies were obtained from Pakistan. Unprocessed whole wheat, corn and rice were included in the test. However, the unprocessed samples did not originate from the same batch as the processed samples. All the foods were ground and incorporated into the test diet (Table 1) at the expense of autoclaved potato starch, to be measured in N-balance experiments with rats.

2.2. Analytical methods

The chemical composition of home and industrially produced baby foods was determined according to standard methods.[11,12] The total caloric value of the diets was determined in IKA-calorimeter and metabolisable energy (ME) was calculated according to Miller and Payne.[13] Amino acid analyses were carried out according to Weidner and Eggum[14] and Eggum.[15] Statistical analyses were based on methods described by Snedecor.[16] All the assays were performed in duplicate.

Table 2. Composition and processing conditions of home-prepared baby foods

Food items	Kichri (g)	Kheer (g)	Halwa Suji (g)	Halwa Suji + Baysen (g)
Rice	30.0	30.0	—	—
Green gram (Dhal)	15.0	—	—	—
Milk (whole)	—	130.0	—	—
Semolina (Suji)	—	—	30.0	20.0
Bengal gram flour (Baysen)	—	—	—	10.0
Sugar	—	30.0	30.0	30.0
Salt	1.0	—	—	—
Vegetable oil (Ghee)	8.0	—	12.0	12.0
Water	67.0	130.0	100.0	100.0
Processing conditions:				
Temperature (°C)	100–105	100–110	150–160	150–160
Time (min)	60	45	20	20

3. Results

3.1. Chemical composition of baby foods

The average values for the chemical composition of home and industrially produced baby foods are shown in Table 3.

The total protein content of home-prepared baby foods varies between 6.1 and 11.4%. Lowest figures were obtained in Halwa Suji and Halwa Suji + Baysen. The protein content of Kichri was similar to Farex, whereas Delhya contained the highest content of protein (13%). All the home-cooked baby foods contained about 18% fat except Kheer (6.8%). Both of the commercial baby foods were very low in fat. Less than 30% of energy intakes from fat may result in a dry and unpalatable diet.[17] In this study Kichri, Halwa Suji and Halwa Suji + Baysen each supplied 32% of the total calories from fat whereas only 14, 3 and 4% of energy intakes were derived from fat of Kheer, Farex and Delhya respectively. Consequently, the energy density in these products is very low. The crude fibre content was very low in all samples. The highest content of ash was found in Kheer (4.1%) and Farex (4.2%). The ME values were highest (482–484 kcal) in Kichri, Halwa Suji and Halwa Suji + Baysen, whereas the lowest value (405 kcal) was observed in Farex. The daily allowances for calcium, phosphorus and iron for 6-month-old infant are 360, 240 and 10 mg respectively.[18] It appears that all the analysed samples of baby foods, except Farex, are far too low in these minerals.

Table 3. Chemical composition (dry basis) of home-prepared and industrially produced baby foods

	g per 100 g					Calories per 100 g		mg per 100 g		
	Protein (N × 6.25)	Fat	Available carbohydrate	Crude fibre	Ash	Total	Metabolisable	Ca	P	Fe
Kichri	11.4	18.6	60.7	1.5	1.7	510	484	51.3	184.7	3.5
Kheer	9.5	6.8	75.6	0.3	4.1	446	424	237.3	206.4	1.3
Halwa Suji	6.1	18.3	73.0	0.5	0.4	508	483	23.6	61.6	1.1
Halwa Suji + Baysen	7.0	18.2	71.7	0.9	0.7	507	482	32.9	82.1	2.1
Farex	11.9	1.6	84.9	0.3	4.2	426	405	943.7	664.9	33.2
Delhya (wheat porridge)	13.0	2.0	81.1	1.8	1.7	445	423	36.0	383.0	3.1

3.2. Protein quality of baby foods

Amino acid composition (Table 4) showed that the lysine content (g per 16 g N) was highest in Kheer (6.2) and was lowest in Halwa Suji (1.5).

Table 4. Amino acid composition (g per 16 g N) of home and industrially produced baby foods

Amino acids	Kichri	Kheer	Halwa Suji	Halwa Suji + Baysen	Farex	Delhya (wheat porridge)
Aspartic acid	10.4	8.0	3.9	1.2	5.5	4.7
Threonine	3.3	3.8	2.3	2.6	3.2	2.6
Serine	4.8	4.9	4.0	4.3	4.9	4.0
Glutamic acid	19.1	21.9	35.8	27.8	31.9	32.7
Proline	4.4	7.8	10.8	7.7	10.4	9.5
Glycine	4.0	2.6	3.1	3.3	3.3	3.9
Alanine	4.8	3.9	2.8	3.3	3.5	3.4
Valine	5.4	5.8	3.8	3.9	4.7	4.1
Isoleucine	4.4	4.8	3.6	3.9	4.1	3.5
Leucine	8.0	9.1	6.7	6.9	8.1	6.6
Tyrosine	3.9	4.6	2.8	2.8	3.8	3.0
Phenylalanine	5.6	4.7	4.6	5.0	4.6	4.3
Lysine	5.4	6.2	1.5	3.5	3.4	2.5
Histidine	2.4	2.4	1.9	2.0	2.3	2.2
Arginine	7.5	4.9	3.5	6.1	4.1	4.6
Methionine	1.7	2.6	1.7	1.7	1.9	1.7
Cystine	1.2	1.2	1.8	1.6	2.1	2.2
Tryptophan	0.8	1.1	0.7	0.7	1.2	1.3

Protein score based on the FAO-scoring pattern[19] (Table 5) indicates that lysine and threonine are the first and second limiting amino acids in Halwa Suji, Halwa Suji + Baysen, Farex and Delhya, whereas threonine and methionine are the first and the second limiting amino acids in Kichri and Kheer, rice based, home-prepared baby foods. Tryptophan is the third limiting amino acid in Kichri, Halwa Suji and Halwa Suji + Baysen, valine in Farex and Delhya and lysine in Kheer.

Results obtained on the effect of home and industrial processing on true protein digestibility (TD), biological value (BV) and net protein utilisation (NPU) are summarised in Table 6.

Table 5. Protein score and limiting amino acids of home and industrially produced baby foods

Baby food	Protein score[a]	Limiting amino acids		
		First	Second	Third
Kichri	74	Threonine	Methionine	Tryptophan
Kheer	77	Threonine	Methionine	Lysine
Halwa Suji	35	Lysine	Threonine	Tryptophan
Halwa Suji + Baysen	71	Lysine	Threonine	Tryptophan
Farex	60	Lysine	Threonine	Valine
Delhya (wheat porridge)	52	Lysine	Threonine	Valine

[a] Based on the FAO/WHO 1973 scoring pattern.

Table 6. Effect of home and industrial processing on the protein quality of baby foods, determined in N-balance experiments with rats

	True digestibility		Biological value		Net protein utilisation		Net dietary protein calorie %	
	(%)	(s)	(%)	(s)	(%)	(s)	(%)	(s)
Kichri	92.0	1.1	71.0	0.8	65.0	1.0	6.1	1.0
Kheer	96.0	0.9	84.0	0.8	81.0	0.8	7.3	0.8
Halwa Suji	99.0	1.1	52.0	0.7	51.0	0.7	2.6	0.7
Halwa Suji + Baysen	99.0	1.0	75.0	1.3	74.0	0.6	4.3	0.6
Farex	94.0	1.0	63.0	0.7	60.0	1.3	7.1	1.3
Delhya (wheat porridge)	97.0	0.6	59.0	1.0	57.0	1.3	7.0	1.3

All the baby foods had a TD above 90% and the highest TD (99%) was observed in Halwa Suji and Halwa Suji + Baysen.

The NPU of Kichri, Kheer and Halwa Suji + Baysen were 65, 81 and 74% for home-prepared baby foods and 60 and 57% respectively for the industrially produced Farex and Delhya. The lowest NPU (51%) was found with Halwa Suji. Net dietary protein calorie per cent (NDp cal%) of all the baby foods were calculated according to Miller and Payne[20] (Table 6). The NDp cal% of home-prepared baby foods varied between 2.6 and 7.3% and the values for Farex and Delhya were 7.1 and 7.0% respectively.

3.3. Protein quality of breakfast cereals

Table 7 reveals the effect of industrial processing on amino acid composition, TD, BV and NPU of breakfast cereals prepared from wheat, corn and rice.

Table 7. Effect of industrial processing on amino acid composition (g per 16 g N), true digestibility (%), biological value (%) and net protein utilisation (%) of breakfast cereals

	Wheat		Corn			Rice	
	Whole	Vermicelli	Whole	Flakes	Puffed	Whole	Krunchies
Aspartic acid	4.6	4.1	5.5	5.4	5.4	8.3	8.1
Threonine	2.8	2.5	3.2	3.2	3.1	3.4	3.2
Serine	4.8	4.1	4.4	4.4	4.3	4.6	4.3
Glutamic acid	34.9	35.1	19.0	22.1	20.3	18.1	19.7
Proline	10.7	10.4	8.5	9.4	8.2	4.3	4.8
Glycine	3.7	3.6	3.4	2.8	3.3	4.2	4.2
Alanine	3.2	3.1	7.2	7.5	7.0	5.3	5.4
Valine	3.8	4.2	4.5	4.3	4.2	5.4	5.5
Isoleucine	3.4	3.6	3.4	3.5	3.3	4.0	4.1
Leucine	6.9	6.8	12.7	13.7	12.4	7.7	8.0
Tyrosine	3.0	3.0	4.0	4.2	3.8	4.6	4.5
Phenylalanine	4.7	4.4	4.5	4.7	4.3	4.8	4.8
Lysine	2.3	1.5	2.5	0.6	1.1	3.4	1.6
Histidine	2.1	1.8	2.7	2.4	2.4	2.1	1.7
Arginine	4.2	3.8	4.4	2.6	2.9	7.6	5.6
Methionine	1.6	1.7	2.1	1.7	1.9	2.9	2.2
Cystine	2.0	2.3	2.0	1.6	1.4	2.0	1.9
Tryptophan	1.0	1.0	0.6	0.4	0.5	1.1	1.0
Nitrogen (%)	1.96	1.83	1.82	1.18	1.86	1.42	1.32
True digestibility	96.0	92.0[a]	95.0	85.0[a]	83.0[a]	100.0	80.0[a]
Biological value	55.0	48.0[a]	61.0	40.0[a]	45.0[a]	71.0	53.0[a]
Net protein utilisation	53.0	44.0[a]	58.0	34.0[a]	37.0[a]	71.0	42.0[a]

[a] $P < 0.001$, significantly different from corresponding value of whole cereal.

As expected lysine was found to be the most affected amino acid during industrial processing with very low values in the processed samples. Industrial processing significantly ($P < 0.001$) reduced the TD, BV and NPU of all the breakfast cereals when compared with the corresponding values of whole cereals. The highest TD, BV and NPU values were found for vermicelli, whereas cornflakes had the lowest values.

Table 8 indicates that lysine is the first limiting amino acid in all the breakfast cereals, threonine is the second limiting amino acid in vermicelli and rice krunchies, and it is tryptophan in cornflakes and puffed corn. Valine is the third limiting amino acid in vermicelli, whereas it is threonine in cornflakes and puffed corn.

Table 8. Protein score and limiting amino acids of breakfast cereals

Sample	Protein score[a]	Limiting amino acids		
		First	Second	Third
Whole wheat	49	Lysine	Threonine	Valine
Vermicelli	32	Lysine	Threonine	Valine
Whole corn	41	Lysine	Tryptophan	Threonine
Cornflakes	11	Lysine	Tryptophan	Threonine
Puffed corn	21	Lysine	Tryptophan	Threonine
Whole rice	58	Lysine	Threonine	Isoleucine
Rice krunchies	29	Lysine	Threonine	

[a] Based on the FAO/WHO 1973 scoring pattern.

4. Discussion

Heat processing is known to affect the nutritive value of protein in various ways. According to Bender,[8] the processing damage to proteins can result from destruction of amino acids by oxidation, loss of palatability, modification of some of the linkages between the amino acids so that their release is delayed during digestion and finally, formation of linkages that are not hydrolysed during digestion.

The processing conditions employed in the present work in home-prepared baby foods indicate that cooking temperature (100–110°C) does not appear to affect the total lysine content of Kichri and Kheer whereas lysine contents of Halwa Suji and Halwa Suji + Baysen are damaged to a greater extent when cooked at 150–160°C. Maillard reaction may be responsible for this loss. Lysine and threonine are the limiting amino acids in all home and industrially produced baby foods and confirm the findings of Khan and Eggum[21] who found similar results with mixed Pakistani diets.

Table 6 indicated that the TD of all the baby foods was above 90% (92–99%) whereas the NPU values except for Kheer (81%) and Halwa Suji + Baysen (74%) ranged from 51–65%. It is possible that amino acids were absorbed from the gut in non-metabolisable forms and excreted in the urine.[22] Formation of toxic substances may also contribute to the reduced nutritive value of materials containing products of the Maillard reaction.[23] The NPU values of home-prepared baby foods, Kichri (65%), Kheer (51%) and Halwa Suji + Baysen (74%) were better than those of the industrially produced foods, Farex (60%) and Delhya (57%). However, Farex and Delhya had NPU values higher than Halwa Suji (51%).

According to Payne,[24] the levels of protein required in terms of protein and energy requirement ratios for different age groups i.e. 6–9 months, 1 year and 2–3 years are 6.9, 5.4 and 5.3 respectively. A comparison with NDp cal% of the baby foods (Table 6), indicates that among the home-prepared baby foods, Kichri and Kheer can meet the given protein requirements of babies from 1 to 3 years and from 6 months to 3 years respectively. Halwa Suji and Halwa Suji + Baysen are not suitable for all these groups. However, both the industrially produced baby foods are, according to Payne,[24] adequate to meet the protein requirement of all different age groups.

It is evident (Table 7) that the lysine and arginine contents of breakfast cereals are severely affected during industrial processing. Lysine, the most heat sensitive amino acid, is reduced by 35% in vermicelli, 76% in cornflakes, 56% in puffed corn and 53% in rice krunchies. It appears that advanced Maillard reactions can destroy large proportions of lysine and arginine.[25] The industrial processing also reduced significantly the TD, BV and NPU of all the breakfast cereals. The TD of vermicelli, cornflakes, puffed corn and rice krunchies reduced 4, 11, 13 and 20% respectively. The BV was lower by 13% in vermicelli, 34% in cornflakes, 26% in puffed corn and 25% in rice krunchies and the NPU of vermicelli, cornflakes, puffed corn and rice krunchies decreased 17, 41, 36 and 41% respectively when compared with the corresponding whole wheat, corn and rice values. The NPU of vermicelli was similar to rice krunchies, similarly there was no difference between the NPU values of cornflakes and puffed corn.

The protein score of the amino acid composition (Table 8) showed that in all cases lysine was the limiting amino acid. This was, of course to be expected in cereal products. The protein score was, however, in all the breakfast cereals remarkably low when compared with the values of the respective whole cereals and agrees with the findings of Dahlqvist *et al.*[7] and Eggum.[3]

Although the contribution of breakfast cereals to protein intake is so small that the loss of BV in the processing operation may not be very significant in developed countries, it may have a significant effect in developing countries where protein intakes are either low or at marginal levels, especially if cereals are consumed without milk. In conclusion, the home and industrial processing has caused a severe damage to the protein quality of Halwa Suji and other breakfast cereals. The optimum processing conditions for different foodstuffs may not be well known, however, it should be possible to improve industrial processing to prevent many industrially-produced foods suffering from protein damage. The manufacturers needs to be informed of the nutritional consequences of reactions that take place during heat processing.

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