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# Nutritional Quality of Maize, Sorghum and Millet

Iftikhar Ali Rana and M. Akmal Khan
Nutrition and Food Quality Laboratory
National Agricultural Research Centre,
Islamabad

## INTRODUCTION

Cereals grains are the dietary mainstay of mankind and provide more than three quarters of man's energy needs and more than one half of his protein needs. Cereals as a class are limiting in the essential amino acid lysine. The second and third limiting amino acids in maize are tryptohan and threonine and in sorghum and millets these are threonine and isoleucine respectively (Khan and Eggum 1979). The annual world production of maize in 1983 was 344 million tons, for sorghum it was 62.5 million tons and for millets it was 29.6 million tons. The annual production of maize, sorghum and millets in Pakistan in the year 1983 was 1 million tons, 0.27 million tons and 0.235 million tons respectively (FAO, 1983).

The plant breeders have succeeded in improving the quantity and quality of protein in maize and sorghum. During the early 1960s two important mutants of maize,opaque-2 and Floury-2 were discovered (Nelson et. al, 1965). These had a higher protein content and protein quality than the normal maize varieties. The purdue research team (Axtell, 1976) have identified two distinctly different genes in sorghum which improve overall protein quality: the naturally occurring high lysine (hl) from Ethiopia and mutant P-271, a chemically induced high lysine mutant. Crosses between these two genes have produced a higher than normal frequency of progeny high in lysine.

COMPOSITION AND PROTEIN QUALITY

Chemical composition, efficiency of protein utilization and digestible energy of maize, millet and sorghum are presented in table 1. Starch is the major carbohydrate of these grains with the highest value for maize (74.0%) and the lowest value for sorghum (67.4%). Both the major fraction of starch (amylose and amylopectin) occur in these cereal grains. The fat content is highest in maize (5.7%) and the lowest (4.5%) in sorghum. Fibre and Ash contents are highest in sorghum. The thiamine and riboflavin contents are low in these cereals whereas the niacin content is relatively high. Sorghum has the highest iron content (10 mg/100 g) while maize has the lowest content (4.0 mg/100 g). The protein digestibility is highest for maize (95%) while the protein digestibility of sorghum is only 84.8%. This is also reflected in the net protein utilization values which are highest for maize and lowest for sorghum. Utilisable protein (UP) is a derived figure and depends upon both protein concentration and protein quality. The UP value for sorghum was lowest due to the low NPU of the grain. The NPU values ranged from 50-58% which means that 50-42% of the ingested nitrogen is excreted in the faces and urine.

ESSENTIAL AMINO ACID PATTERN

Tabel 2 shows the essential amino acid pattern of maize, sorghum and millets as compared with the FAO/WHO pattern for reference protein. Thus all these cereals are deficient in lysine, threonine and isoleucine for the child. Only the modified opaque-2 variety of maize meets the lysine and isolucine requirements of the child. Normal maize varieties are also limiting in tryptophan for the child but modified opaque-2 variety compares favourably with FAO/WHO reference pattern in this respect. All the other essential amino acids are present in adequate amounts in these three cereals.

HUMAN REQUIREMENTS

The estimates of human requirements of proteins from maize, sorghum and millets are presented in table 3. It can be seen that the requirements for protein in terms of these three cereals are much higher than the requirements for reference egg or milk proteins. The higher requirements are due to the fact that these three cereals have much lower protein quality (NPU) when compared with the reference proteins and thus higher amounts have to be consumed to meet protein needs. This can be a limiting factors as the growing child may be unable to consume large amounts of cereals to meet his protein needs.

PROTEIN FRACTIONS

Thevarious protein fractions of maize, sorghum and millets are shown in table 4. Thus the millets have higher concentrations of albumins and globulins as compared to maize and sorghum, while the prolamine and glutelins contents of maize are higher than those of millets and sorghum. The extraction of proteins from these cereals was not complete and 52.6 - 15.9% of the total protein could not be extracted.

EFFECT OF FERTILIZER ON AMINO ACID CONTENT AND PROTEIN QUALITY

The effect of fertilizer on amino acid content and protein quality of sorghum and millets is shown in table 5. No such data was available for maize. These data show that the content (mg/gN) of isoleucine and leucine increases, with increase in the rate of N fertilizer application. The concentrations of lysine however decreases with increase in rate of N fertilizer application in case of sorghum and millets. The concentration of tryptophan decreases in sorghum while it increases some-what in millets as the amount on N fertilizer applied/hectare is increased.

Maximum weight gain of animals is obtained on sorghum produced on soil treated with minor elements while there is some increase in weight gain in animals fed millets as the amount of N fertilizer/hectare is increased. Protein efficiency ratio (PER) is highest when the weanlang rats were fed sorghum produced on soil treated with minor elements. The PER values of millet however decrease as the rate of fertilizer application is increased due to decrease in its lysine content.

CHEMICAL COMPOSITION OF BREAD

The chemical composition of the bread made from maize, millet and sorghum is shown in table 6. Thus the bread from millets has highest protein content (12.2%) while the bread from sorghum the lowest protein content (6.9%). The available carbohydrate content was lower in sorghum bread as compared to bread from maize and millets. The crude fibre content was however highest (4.8%) in sorghum bread. The calcium and iron content of bread from sorghum was higher amongest these three cereals, however the tannin content of bread from sorghum was also 2-4 times the tannin content of bread from maize and millets. There was not much difference in the total and metabalizable energy content of the bread preparations of these cereals grains.

The fatty acid composition of breads prepared from maize, sorghum and millets is shown in table 7. The major proportion of fatty acids (74.4-84.2%)in these cereals was unsaturated and the highest amount of unsaturated fatty acids was present in maize.

PROTEIN QUALITY OF BREAD

The amino acid composition of flour and bread from maize, sorghum and millets is shown in table 8. The amino acid composition of flour differed from that of bread due to losses in baking. Lysine, which is the most heat sensitive amino acid was reduced slightly in bread. The content of threonine was also reduced in sorghum and millet breads. Tryptophan content was reduced in maize and milllet breads.

Protein rcores are presented in table 9. Thus lysine is the first limiting amino acid in all the breads. Threonine is the second limiting amino acid in millet and sorghum while tryptophan is the second limiting amino acid in maize. Protein scores are the lowest for maize and higher for sorghum and millets. The flours from maize, sorghum and millets have higher protein scores than breads prepared from these cereals. This is an indication of damage to heat sensitive amino acids during baking.

Results obtained on the effect baking on true protein digestibility (TD), biological value (BV) and net protein utilisation (NPU) are summarised in table 10. The TD of maize and millet breads was not affected by baking but was significantly lower in sorghum bread compared with the sorghum flour. The BV of maize bread was significantly lower while that of millet and sorghum breads was hgiher than the value for the corresponding flours. The NPU of maize bread was significantly reduced while that of millet and sorghum breads was not significantly changed. The NDPCal% value of all the breads was below 6.6 and cannot meet the protein requirement of different age groups.

## INDUSTRIAL PROCESSING

The effect of industrial processing on the protein quality of maize products is shown in table 11. Thus industrial processing for the production of puffed corn and corn flakes greatly reduces the lysine content of these products as compared to whole corn. Tryptohan content is also somewhat reduced. The protein quality of these corn products falls as a results of industrial processing. Corresponding data for industrial processing of sorghum and milelt products where not available.

## NUTRITIONAL GOALS FOR BREEDERS

Cereal proteins are highly important both because of their nutritional value and their functional properties. To maintain and improve protein quality and quantity, it is continually necessary to breed new varieties. Traditional breeding technologies, which have been and continue to be highly successful, involve crosses, mutations, selection and screening. These approaches may soon, however be increasingly augmented with modern approaches such as recombinant DNA technology, tissue culture and protoplast fusion which open exciting new avenues from protein improvement.

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In maize, breding for increased protein content is desirable, but care should be taken that this is not accompanied by a reductions in starch yield and protein quality. In sorghum, the tannin content must be considered, since some varieties with high tannin levels have a low nutritional value. As with maize, the leucine content and islolencine/leucine ratio may cause nutritional imbalance. In millet, breeding should be directed to increase the content of lysine while maintaining adequate protein and yield levels. More research is needed to solve the problems of low digestibility and antinutritional factors.

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TABLE-1

CHEMICAL COMPOSITION (ON DRY BASIS) AND BIOLOGICAL DATA OF MAIZE, SORGHUM AND MILLETS (MCCANCE AND WIDDOWSON, 1970; KHAN AND EGGUM, 1978)

| GRAIN VARIETY | MAIZE | SORGHUM | MILLETS |
|---|---|---|---|
| PROTEIN% | 11.4 | 9.6 | 13.4 |
| FAT% | 5.7 | 4.5 | 5.5 |
| AVAILABLE CARBOHYDRATE% | 74.0 | 67.4 | 73.7 |
| CRUDE FIBRE% | 2.3 | 4.8 | 1.8 |
| ASH% | 1.6 | 3.0 | 1.8 |
| CALORIES/100g. | 461 | 447 | 459 |
| THIAMIN(mg./100g) | 0.37 | 0.38 | 0.73 |
| RIBOFLAVIN (mg./100g) | 0.12 | 0.15 | 0.38 |
| NIACIN (mg./100g) | 2.2 | 3.9 | 2.3 |
| Fe. (mg./100g) | 4.0 | 10.0 | 8.0 |
| Zn. (mg./100g) | 3.0 | 2.0 | 3.0 |
| LYSINE (g./16g. N) | 2.5 | 2.7 | 2.7 |
| TRYPTOPHAN (g./16g. N) | 0.6 | 1.0 | 1.3 |
| THREONINE (g./16g. N) | 3.2 | 3.3 | 3.2 |
| TANNIN% | 0.5 | 1.9 | 0.7 |
| PROTEIN DIGESTIBILITY% | 95.0 | 84.8 | 93.9 |
| BIOLOGICAL VALUE% | 61.0 | 59.2 | 60.0 |
| NET PROTEIN UTILISATION% | 58.0 | 50.0 | 56.0 |
| UTILISABLE PROTEIN% | 6.6 | 4.8 | 7.5 |
| DIGESTIBLE ENERGY% | 87.2 | 79.9 | 87.2 |

TABLE-2

ESSENTIAL AMINO ACID COMPOSITION OF MAIZE, MILLET AND SORGHUM (KHAN AND EGGUM, 1978, FAO/WHO 1973)

(g./16g. N)

| ESSENTIAL AMINO ACID | MAIZE | OPAQUE-2 MODIFIED | SORGHUM | MILLETS | FAO/WHO PATTERN | |
|---|---|---|---|---|---|---|
| | | H.208 | | | CHILD | ADULT |
| LYSINE | 2.5 | 5.0 | 2.7 | 2.7 | 5.5 | 2.2 |
| TRYPTOPHAN | 0.6 | 1.1 | 1.0 | 1.3 | 1.0 | 0.6 |
| THREONINE | 3.2 | 3.7 | 3.3 | 3.2 | 4.0 | 1.3 |
| ISOLEUCINE | 3.4 | 4.4 | 3.6 | 3.8 | 4.0 | 1.8 |
| LEUCINE | 12.7 | 12.7 | 11.2 | 8.9 | 7.0 | 2.5 |
| TRYOSINE | 4.0 | - | 3.6 | 3.0 | - | - |
| PHENYLALANINE | 4.5 | 5.3 | 4.4 | 4.5 | 2.4 | 1.5 |
| HISTIDINE | 2.7 | - | 2.2 | 2.1 | - | - |
| METHIONINE | 2.1 | 3.2 | 2.3 | 2.2 | 3.5+ | 2.4+ |
| CYSTINE | 2.0 | - | 2.2 | 2.2 | - | - |
| VALINE | 4.5 | - | 4.7 | 4.8 | 5.0 | 0.8 |

\+ Total surplur aming aids.

Table-3

ESTIMATES FOR HUMAN REQUIREMENT OF PROTEINS FROM MAIZE, SORGHUM AND MILLETS (FAO/UNU 1984)

(gms./Kg weight/day)

| AGE GROUP | REFERENCE PROTEIN | MAIZE | SORGHUM | MILLET |
|---|---|---|---|---|
| 3-6 months | 1.85 | 3.19 | 3.45 | 3.14 |
| 6-9 months | 1.65 | 2.70 | 3.07 | 2.80 |
| 9-12 months | 1.5 | 2.46 | 2.79 | 2.54 |
| 1-2 years | 1.2 | 1.96 | 2.23 | 2.04 |
| 3-5 years | 1.1 | 1.80 | 2.04 | 1.87 |
| 5-7 years | 1.0 | 1.64 | 1.86 | 1.70 |
| 10-12 years | | | | |
| Male | 1.0 | 1.64 | 1.86 | 1.70 |
| Female | 1.0 | 1.64 | 1.86 | 1.70 |
| 12-14 years | | | | |
| Male | 1.0 | 1.64 | 1.86 | 1.70 |
| Female | 0.95 | 1.56 | 1.77 | 1.61 |
| 14-16 years | | | | |
| Male | 0.95 | 1.56 | 1.77 | 1.61 |
| Female | 0.90 | 1.48 | 1.68 | 1.53 |
| 16-18 years | | | | |
| Male | 0.90 | 1.48 | 1.68 | 1.53 |
| Female | 0.80 | 1.31 | 1.49 | 1.36 |
| Adults | | | | |
| Male | 0.75 | 1.23 | 1.40 | 1.27 |
| Female | 0.75 | 1.23 | 1.40 | 1.27 |
| Pregnancy | + 6.0 | | | |
| Lactation | +13.0 | | | |

TABLE-4

PERCENTAGE OF PROTEIN FRACTIONS IN MAIZE, SORGHUM AND MILLET PROTEIN (PUSHPAMMA, 1968)

| PROTEINS | MAIZE | SORGHUM | MILLET |
|---|---|---|---|
| ALBUMINS | 13.3 | 11.2 | 15.2 |
| GLOBULINS | 10.3 | 9.7 | 11.8 |
| PROLAMINES | 21.8 | 7.6 | 17.1 |
| GLUTELINS | 38.7 | 18.9 | 25.3 |
| RESIDUAL | 15.9 | 52.7 | 30.4 |
| TOTAL PROTEIN EXTRACTED | 84.1 | 47.4 | 69.6 |

## TABLE-5

EFFECT OF FERTILIZER TREATMENT ON AMINO ACID CONTENT OF PROTEIN, WEIGHT GAIN AND PER OF WEANLING, RATS (ARAGON AND BREASSANI, 1965; GANRY AND BIDEAU, 1974)

| | | SORGHUM Kg/HECTARE | | | MILLETS Kg/HECTARE | | |
|---|---|---|---|---|---|---|---|
| AMINO ACIDS | | $N_0$ | $N_{50}$ | $N_{135}$ | $N_o$ | $N_{80}$ | $N_{160}$ |
| ISOLEUCINE(mg/g. N) | | 252 | 265 | 264 | 244 | 250 | 262 |
| LEUCINE (mg./g. N) | | 812 | 897 | 911 | 531 | 550 | 544 |
| LYSINE (mg./g. N) | | 157 | 130 | 126 | 194 | 169 | 162 |
| TRYOTOPHAN (mg./g. N) | | 79 | 71 | 66 | 63 | 69 | 73 |
| RAT FEEDING TRIALS (OVER 35 DAYS) | CONTROL | MINOR ELEMENTS | NPK | ORG. FERTILIZER | $N_0$ | $N_{90}$ | $N_{120}$ |
| WEIGHT GAIN (gms.) | 18.9 | 23.5 | 12.5 | 10.9 | 21.0 | 24.5 | 25.6 |
| PROTEIN EFFICIENCY RATIO | 0.79 | 0.93 | 0.65 | 0.59 | 1.77 | 1.20 | 1.16 |

TABLE-6

CHEMICAL COMPOSITION (DRY BASIS) OF FLOUR AND BREAD SAMPLES (KHAN AND EGGUM, 1978)

| | g.PER 100 g | | | | | CALORIES PER 100g | | mg PER 100 g | | | | g PER 100g |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | PROTEIN (Nx5.7) | FAT | AVAILABLE CARBOHYDRATE | CRUDE FIBRE | ASH | TOTAL | METABO-LIZABLE | CA | P | S | FE | TANNIN |
| MAIZE FLOUR | 10.4 | 5.7 | 74.4 | 2.3 | 1.6 | 461 | 438 | 16.8 | 330.3 | 29.6 | 4.2 | 0.48 |
| MAIZE BREAD | 10.5 | 5.2 | 72.5 | 2.6 | 1.6 | 455 | 432 | 27.1 | 325.0 | 31.4 | 4.5 | 0.35 |
| MILLET FLOUR | 12.2 | 5.5 | 72.7 | 1.8 | 1.8 | 459 | 436 | 22.5 | 338.2 | 33.8 | 8.1 | 0.72 |
| MILLET BREAD | 12.2 | 5.4 | 71.1 | 1.8 | 1.7 | 455 | 432 | 30.3 | 335.6 | 43.6 | 6.2 | 0.62 |
| SORGHUM FLOUR | 6.9 | 4.5 | 67.4 | 4.8 | 3.0 | 447 | 425 | 44.8 | 313.9 | 25.9 | 10.1 | 0.90 |
| SORGHUM BREAD | 6.9 | 4.9 | 64.8 | 4.8 | 2.9 | 446 | 424 | 53.9 | 323.9 | 35.6 | 10.7 | 1.67 |

TABLE- 7

FATTY ACID COMPOSITION (g PER 100g MEASURED FATTYACIDS) OF FLOUR AND BREAD (KHAN AND EGGUM, 1978)

| FATTY ACIDS | MAIZE | | SORGHUM | | MILLET | |
|---|---|---|---|---|---|---|
| | FLOUR | BREAD | FLOUR | BREAD | FLOUR | BREAD |
| 12:0 | 0 | 0 | 0 | 0.4 | 0 | 0 |
| 14:0 | 0.1 | 0.1 | 0.1 | 0.3 | 0.1 | 0.1 |
| 16:0 | 15.8 | 15.7 | 17.4 | 18.0 | 20.1 | 20.4 |
| 16:1 | 0.4 | 0 | 0 | 0.9 | 0.6 | 0.6 |
| 18:0 | 2.4 | 2.1 | 1.4 | 2.0 | 2.9 | 2.9 |
| 18:1 | 33.0 | 32.7 | 35.4 | 35.7 | 25.5 | 26.3 |
| 18:2 | 45.9 | 47.2 | 43.3 | 40.9 | 45.8 | 44.7 |
| 18:3 | 2.3 | 2.2 | 1.5 | 1.8 | 5.0 | 4.9 |

TABLE-8

AMINO ACID COMPOSITION (g PER 16g N) OF FLOUR AND BREAD, (KHAN AND EGGUM, 1978)

| AMINO ACID | MAIZE | | SORGHUM | | MILLET | |
|---|---|---|---|---|---|---|
| | FLOUR | BREAD | FLOUR | BREAD | FLOUR | BREAD |
| VALINE | 4.5 | 4.5 | 4.7 | 4.7 | 4.8 | 4.7 |
| ISOLEUCINE | 3.4 | 3.5 | 3.6 | 3.6 | 3.8 | 3.8 |
| LEUCINE | 12.7 | 12.8 | 11.2 | 11.1 | 8.9 | 8.8 |
| TYROSINE | 4.0 | 4.1 | 3.6 | 3.5 | 3.0 | 3.0 |
| PHENYLALANINE | 4.5 | 4.6 | 4.4 | 4.4 | 4.5 | 4.4 |
| LYSINE | 2.5 | 2.4 | 2.7 | 2.5 | 2.7 | 2.5 |
| HISTIDINE | 2.7 | 2.7 | 2.2 | 2.0 | 2.1 | 2.0 |
| ARGININE | 4.4 | 4.3 | 4.6 | 4.0 | 4.5 | 4.3 |
| METHIONINE | 2.1 | 2.1 | 2.3 | 2.3 | 2.2 | 2.2 |
| CYSTINE | 2.0 | 1.9 | 2.2 | 2.3 | 1.9 | 1.7 |
| TRYPTOPHAN | 0.6 | 0.5 | 1.0 | 1.0 | 1.3 | 1.2 |

TABLE-9

PROTEIN SCORE AND THE LIMITING AMINO ACIDS OF FLOUR AND BREAD SAMPLES (KHAN AND EGGUM, 1978)

| SAMPLE | PROTEIN SCORE | LIMITING AMINO ACIDS | | |
|---|---|---|---|---|
| | | FIRST | SECOND | THIRD |
| MAIZE FLOUR | 41 | LYSINE | TRYPTOPHAN | THREONINE |
| MAIZE BREAD | 39 | LYSINE | TRYPTOPHAN | THREONINE |
| SORGHUM FLOUR | 46 | LYSINE | THREONINE | ISOLEUCINE |
| SORGHUM BREAD | 43 | LYSINE | THREONINE | ISOLEUCINE |
| MILLET FLOUR | 49 | LYSINE | THREONINE | ISOLEUCINE |
| MILLET BREAD | 46 | LYSINE | THREONINE | ISOLEUCINE |

TABLE-9

PROTEIN SCORE AND THE LIMITING AMINO ACIDS OF FLOUR AND BREAD SAMPLES (KHAN AND EGGUM, 1978)

| SAMPLE | PROTEIN SCORE | LIMITING AMINO ACIDS | | |
|---|---|---|---|---|
| | | FIRST | SECOND | THIRD |
| MAIZE FLOUR | 41 | LYSINE | TRYPTOPHAN | THREONINE |
| MAIZE BREAD | 39 | LYSINE | TRYPTOPHAN | THREONINE |
| SORGHUM FLOUR | 46 | LYSINE | THREONINE | ISOLEUCINE |
| SORGHUM BREAD | 43 | LYSINE | THREONINE | ISOLEUCINE |
| MILLET FLOUR | 49 | LYSINE | THREONINE | ISOLEUCINE |
| MILLET BREAD | 46 | LYSINE | THREONINE | ISOLEUCINE |

TABLE-10

EFFECT OF BAKING ON THE PROTEIN QUALITY OF PAKISTANI BREADS
(KHAN AND EGGUM, 1978)

| | TRUE DIGESTIBILITY % | BIOLOGICAL VALUE % | NET PROTEIN UTILISATION % | NET DIETARY PROTEIN CALORIES % |
|---|---|---|---|---|
| MAIZE FLOUR | 95.0 | 61.0 | 58.0 | 5.5 |
| MAIZE BREAD | 94.9 | 57.0[a] | 53.0[a] | 5.2 |
| SORGHUM FLOUR | 56.0 | 91.0 | 51.0 | 3.3 |
| SORGHUM BREAD | 52.0[a] | 96.0[a] | 50.0 | 3.3 |
| MILLET FLOUR | 93.0 | 60.0 | 56.0 | 6.3 |
| MILLET BREAD | 92.0 | 62.0 | 57.0 | 6.4 |

[a]P 0.001 SIGNIFICANTLY DIFFERENT FROM CORRESPONDING VALUE OF FLOUR.

Table-11

EFFECT OF INDUSTRIAL PROCESSING ON THE PROTEIN QUALITY OF CORN BREAKFAST CEREALS (KHAN AND EGGUM, 1979

| | WHOLE CORN | CORN FLAKES | PUFFED CORN |
|---|---|---|---|
| ISOLEUCINE | 3.4 | 3.5 | 4.2 |
| LEUCINE | 12.7 | 13.7 | 12.4 |
| TYROSINE | 4.0 | 4.2 | 3.8 |
| PHENYLALANINE | 4.5 | 4.7 | 4.3 |
| LYSINE | 2.5 | 0.6 | 1.1 |
| HISTIDINE | 2.7 | 2.4 | 2.4 |
| METHIONINE | 2.1 | 1.7 | 1.9 |
| CYSTINE | 2.0 | 1.6 | 1.4 |
| TRYPTOPHAN | 0.6 | 0.4 | 0.5 |
| THREONINE | 3.2 | 3.2 | 3.1 |
| VALINE | 4.5 | 4.3 | 4.2 |
| TD | 95.0 | 85.0 | 83.0 |
| BV | 61.0 | 40.0 | 45.0 |
| NPU | 58.0 | 34.0 | 37.0 |