TABLE 2. Chemical Composition of Pigeon-pea, and Chick-pea Dhal[a] Samples

Constituent	Pigeon-pea[b]			Chick-pea[b]		
	No. of samples	Range	Mean	No. of samples	Range	Mean
Protein (%)	12,828[c]	13.2–26.5[c]	20.4[c]	17,679[c]	10.6–31.1[c]	20.5[c]
	8,575	15.1–31.5	23.2[d]	32	20.6–30.5	25.4[d]
Starch (%)	10	56.3–64.1	60.7	32	51.1–58.1	55.6
Soluble sugars (%)	10	4.7–5.7	5.2	32	4.1–6.0	5.1
Fat (%)	10	1.2–2.2	1.6	32	3.5–6.8	5.5
Crude fibre (%)	10	1.0–1.2	1.2	32	0.7–1.3	1.1
Ash (%)	10	3.3–4.3	3.9	32	2.1–3.7	2.9

a. Decorticated split cotyledons.
b. All values except *c* and *d* are given on a dry-weight basis.
c. Whole-seed samples.

In the largely cereal- and legume-based diet of the Indian population, legumes serve as one of the major suppliers of protein. From the large collection of germplasm accessions of pigeon-pea and chick-pea from various parts of the world available at ICRISAT, several thousand samples have been analysed for their protein content and a few for their proximate composition as well (table 2). The mean protein content of pigeon-pea whole seed was 20.4 per cent and that of dhal (decorticated split cotyledons) 23.2 per cent; that of chick-pea whole seed was 20.5 per cent (Jambunathan and Singh 1979, 1980). Cultivars of high-protein content could be potential sources for the development of high-protein lines. So could the wild relatives of pigeon-pea and chick-pea: the protein content in dhal samples of wild relatives of pigeon-pea such as *Atylosia*, *Flemingia*, and *Rhynchosia* spp. ranged between 28.3 and 30.5 per cent (Singh et al. 1981), while some wild relatives of chick-pea showed a protein range from 25.6 to 31.7 per cent.

The quality of a protein may be estimated by comparing its amino acid composition with standard reference patterns (FAO/WHO, 1973), the most limiting amino acid presumably determining the nutritive value. Generally the amino acid score is calculated as fellows:

$$\text{Amino acid score} = \frac{\text{mg of amino acid in 1 g of test protein}}{\text{mg of amino acid in 1 g of reference protein}} \times 100.$$

The lowest score obtained for any essential amino acid may be taken as a first approximation to the probably efficiency of utilization of the test protein by children (FAO/WHO 1973). Applying calculation to the essential amino acid composition of sorghum, as shown in table 3, it is clear that by far the most limiting amino acid is

TABLE 3. Protein Content and Essential Amino Acid Composition of Sorghum and Pearl Millet Grains[a]

Amino acids	Sorghum			Amino acid score	Pearl millet			Amino acid score	FAO/WHO (1973) pattern (g/16 g N)
	No. of samples	Range (g/16 g N)	Mean (g/16 g N)		No of samples	Range (g/16 g N)	Mean (g/16 g N)		
Lysine	412	1.06–3.64	2.09	38	280	1.59–3.80	2.84	52	5.5
Threonine	29	2.12–3.94	3.21	80	29	3.17–5.66	4.07	102	4.0
Valine	29	3.84–6.93	5.40	108	29	4.38–7.67	6.01	120	5.0
Methionine + cystine	24	1.80–2.69	2.36	67	29	1.43–3.96	2.71	77	3.5
Isoleucine	29	2.85–5.05	4.17	104	29	3 70–6.34	4.56	114	4.0
Leucine	29	10.12–17.60	14.67	210	29	8.62–14.8	12.42	177	7.0
Phenylalanine + tyrosine	29	6.11–10.72	8.87	148	29	6.54–10.81	8.49	142	6.0
Protein (%)	412	4.60–20.25	11.98		280	6.40–24.25	12.30		

a. Determined by ion exchange chromatography.

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INTERFACES BETWEEN AGRICULTURE, NUTRITION, AND FOOD SCIENCE

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THE UNITED NATIONS UNIVERSITY

GRAIN QUALITY OF SORGHUM, PEARL MILLET, PIGEON-PEA, AND CHICK-PEA

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Abstract

*The results of analyses of sorghum (*Sorghum bicolor *(L.) Moench), pearl millet (*Pennisetum americanum *(L.), pigeon-pea (*Cajanus cajan *(L.) Millsp.), and chick-pea (*Cicer arietinum *(L.)), for their chemical composition—including protein content and essential amino acid composition—are discussed. The distribution patterns of various protein fractions in these grains and the levels of some of the anti-nutritional factors present in pigeon-pea and chick-pea are presented. The results of a survey that was carried out in India to study the utilization of these crops, which included the milling characteristics of pigeon-pea and chick-pea, and the relationships between certain physico-chemical characteristics and cooking quality, are discussed.*

There are several components to grain quality, such as visual quality; nutritional quality, including digestibility and bio-availability of nutrients; anti-nutritional factors; milling characteristics; cooking quality; consumer acceptability; and storage stability. Grain quality deserves as important a place in evaluation of new varieties as high yield and yield stability. Grain produced in a farmer's field passes through several transformations before it is consumed in the form of food. To ensure that these transformations are accomplished efficiently and with minimum nutrient loss, better interactions between different disciplines are needed, and an understanding of various aspects of grain quality becomes vital. This report describes the progress that has been made at ICRISAT in understanding some components of grain quality in sorghum, pearl millet, pigeon-pea, and chick-pea.

Nutritional Quality

Protein Quantity and Quality

Sorghum and pearl millet are staple foods that supply a major proportion of calories and protein to large segments of the populations living in the semi-arid tropical regions

TABLE 1. Seed Weight and Chemical Composition of Sorghum and Pearl Millet Grain

Constituent	Sorghum			Pearl millet		
	No. of samples	Range	Mean[a]	No. of samples	Range	Mean[a]
100-seed weight (g)	100	1.3–5.7	2.8	36	0.48–1.01	0.75
Protein (%)	34,389	4.4–21.1	11.4[b]	20,704	5.8–20.9	10.6[c]
	100	10.6–18.5	14.1			
Starch (%)	100	55.6–75.2	70.8	36	63.1–78.5	71.6
Soluble sugars (%)	100	0.8–4.2	1.3	36	1.4–2.6	2.1
Crude fibre (%)	100	1.0–3.4	1.9	36	1.1–1.8	1.3
Fat (%)	100	2.1–7.6	3.3	36	4.1–6.4	5.1
Ash (%)	100	1.6–3.3	2.1	36	1.1–2.5	1.9

a All values except *b* and *c* are given on a dry-weight basis.
b Based on 10,479 cultivars.
c. Based on 5,377 cultivars.

of Africa and Asia. Hulse et al. (1980) have published an exhaustive review of the chemical composition and nutritive value of sorghum and many millets. Sorghum and millet grain samples analysed in our laboratory exhibited a wide range in chemical composition (table 1). No attempt was made in these analyses to study the genotype-environment interactions.

Protein content, which showed a wide variation, represents the results of analysis of samples obtained from high fertility, low fertility, unirrigated, and irrigated fields. It should be noted that the starch values reported were based on actual analysis and were not calculated values obtained by difference. The wide variability in chemical composition underscores the importance of periodically analysing representative samples of grain from the farmer's field, as normally grown, at low-fertility levels, so that a rough estimate of the availability of protein and other nutrients can be made.

A study conducted at ICRISAT using the two high-protein, high-lysine sorghums, IS-11167 and IS-11758, as parents, suggested that the high-lysine gene may not be stable in normal seed with a plump endosperm background (Riley 1980). However, further intensive study is needed to understand the reasons for this, and possibly to modify the causative factors that hamper the transfer of the high-lysine gene to normal plump background. Analysis of yield and protein contents in cultivars obtained from four locations indicated that, in pearl millet, it should be possible to select for increased protein content without detriment to grain yield or grain weight (ICRISAT 1980).

TABLE 4. Protein Content and Essential Amino Acid Composition of Pigeon-pea and Chick-pea Dhal Samples[a]

Amino acids	Pigeon-pea			Amino acid score	Chick-pea			Amino acid score	FAO/WHO (1973) pattern (g/16 g N)
	No. of samples	Range (g/16 g N)	Mean (g/16 g N)		No. of samples	Range (g/16 g N)	Mean (g/16 g N)		
Lysine	47	6.22–7.84	7.00	127	34	5.23–8.48	6.99	127	5.5
Threonine	47	2.74–4.40	3.81	95	34	2.08–4.60	3.59	90	4.0
Valine	47	3.23–6.32	4.59	92	34	3.88–5.27	4.43	89	5.0
Methionine + cystine[b]	65	1.53–2.88	2.04	58	57	1.72–2.76	2.34	67	3.5
Isoleucine	47	2.60–4.39	3.88	97	34	3.19–5.01	4.10	103	4.0
Leucine	47	5.62–9.60	8.16	117	34	6.11–9.48	7.93	113	7.0
Phenylalanine + tyrosine	47	8.31–16.09	12.73	212	34	5.57–9.74	8.39	140	6.0
Tryptophan[c]	58	0.59–0.96	0.74	74	40	0.73–1.64	1.15	115	1.0
Protein (%)	65	18.8–31.3	24.2		57	16.0–31.7	22.4		

Determined by:
a. Ion exchange chromatography.
b. Performic acid oxidation.
c. Alkaline hydrolysis.

lysine (amino acid score 38), followed by methionine and cystine (67), and threonine (80). In pearl millet, lysine (52), followed by methionine and cystine (77), are the limiting amino acids. The high level of leucine present in sorghum has been implicated in the human disease, pellagra (Hulse et al. 1980). It has been recognized that to improve the nutritional quality of sorghum and pearl millet, it would be desirable—if resources were available—to analyse the germplasm accessions of these two crops for protein and lysine contents and methods for rapid analysis are available (Jambunathan 1980).

Amino acid composition of pigeon-pea dhal samples (table 4) show that the limiting amino acids are methionine and cystine (chemical score 58), tryptophan (74), followed by valine (92), threonine (95), and isoleucine (97). In chick-pea, methionine, and cystine (67) followed by valine (89) and threonine (90) are the limiting amino acids. Surprisingly, tryptophan was not observed to be the limiting amino acid in chick-pea (chemical score 115). However, since the range is large, indicating wide variability, and as no effort was made to study the genotype-environment interaction in these analyses, the data should be treated with caution before drawing any firm conclusions. Our results indicate that screening for either methionine or cystine would be sufficient, as these two amino acids are highly correlated with each other when expressed either as a percentage of protein or as a percentage of sample (Jambunathan and Singh 1982). Using rapid colorimetric procedures, we have estimated methionine content in about 500 chick-pea germplasm accessions (range 0.81–1.59; mean 1.16 g/16 g N) and about 150 pigeon-pea germplasm accessions (range 0.70–1.48; mean 1.08 g/16 g N) and tryptophan content in about 100 chick-pea accessions (range 0.76–1.27; mean 1.05 g/16 g N) and about 60 pigeon-pea accessions (range 0.64–0.95; mean 0.75 g/16 g N) (Jambunathan et al. unpublished data).

The protein quality of sorghum and millet results from the different proportions of the various protein fractions in the grain. Protein fractionation of these cereals is shown in table 5. Fractions II and III are very low in lysine concentration. In high-lysine sorghum, the proportion of these two fractions is lower and that of the first fraction higher than in normal sorghum, thus improving its overall protein quality (Jambunathan 1980).

The protein quality of legumes is likewise related to the proportions of various protein classes. The proportions of fractions in the whole seed and cotyledon of chick-pea and pigeon-pea are shown in table 6. The methionine plus cystine contents of various cotyledon protein fractions show wide variability. Globulin is the major protein component in pigeon-pea and chick-pea. Since its content of methionine plus cystine is rather low, there is an overall deficiency of sulphur amino acids in the whole grain.

Digestibility and Bio-availability

Chemical composition and amino acid composition give only an approximation of

TABLE 5. Nitrogen Distribution in Sorghum and Pearl Millet Grain (percentage of total nitrogen)

Fraction	Sorghum[a]		Pearl millet[b]	
	Range	Mean	Range	Mean
I Albumin and globulin	17.1–17.8	17.4	22.6–26.6	25.0
II Prolamin	5.2–8.4	6.4	22.8–31.7	28.4
III Cross-linked prolamin	18.2–19.5	18.8	1.8–3.4	2.7
IV Glutelin-like	3.4–4.4	4.0	4.7–7.2	5.5
V Glutelin	33.7–38.3	35.7	16.4–19.2	18.4
VI Residue	10.4–10.7	10.6	3.3–5.1	3.9
Total	91.2–94.0	92.9	78.6–87.5	83.9

a. Based on three genotypes, M.35-1, CSH-8, and CSV-3.
b. Based on four genotypes, PHB-14, BK-560, WC-C75, and Ex-Bornu.

TABLE 6. Nitrogen Distribution and Levels of Methionine Plus Cystine Content in Pigeon-pea and Chick-pea Grain (percentage of total nitrogen)

Fraction	Pigeon-pea (Hy-3C)		Chick-pea (G-130)	
	Whole seed	Cotyledon[a]	Whole seed	Cotyledon[a]
Albumin	10.2	11.4 (4.9)[b]	12.6	15.9 (5.3)
Globulin	59.9	64.5 (1.7)	56.6	62.7 (1.8)
Glutelin	17.7	18.2 (2.3)	18.1	17.5 (2.6)
Prolamin	3.0	3.5 (0.5)	2.8	2.3 (0.4)
Residue	5.3	1.8	4.9	1.0
Total	96.1	99.4	95.0	99.4

a. Embryo was removed.
b. Figures in parentheses show methionine + cystine content (g/16 g N) determined by ion exchange chromatography

animals and, if possible, children. MacLean et al. (1981) conducted a feeding study on children in Peru, using two high-lysine and two conventional varieties of sorghum as the sole source of nitrogen. The mean absorption and retention of nitrogen from the sorghum diet were reported to be 46 ± 17 per cent and 14 ± 10 per cent of intake, respectively, against values of 81 ± 5 per cent and 38 ± 3 per cent, respectively, for casein under similar conditions. This indicates that sorghum is a poor source of nitrogen for children. To our knowledge, no similar studies have been carried out with pearl-millet, pigeon-pea, or chick-pea diets. Axtell et al. (1981) have reported that protein from uncooked sorghum has high pepsin digestibility, which was greatly reduced after cooking; however, fermentation of flour improved the pepsin digestibility, indicating that various processing methods should be kept in view while evaluating the grain.

Mineral Elements

Nutritional studies among people of the semi-arid tropics show evidence of deficiencies in calcium, iron, and zinc, all of which elements are rendered insoluble by phytic arid (Hulse et al. 1980). Sorghum shows a wide range for these mineral elements (Jambunathan 1980), but the effects of environment and other agronomic factors must be studied in detail before any conclusion is drawn. The analyses revealed interesting variations in the chemical and mineral element composition of *desi* (small; coloured seed coat) and *kabuli* (large; white seed coat) types of chick-pea cultivars grown at Hissar (Haryana, India). Desi chick-pea had a higher seed coat percentage and fibre content than kabuli. The calcium and iron contents of the kabuli seed coat, in particular, were much higher than those of the desi seed coat, and a few other minerals also showed significant differences (Jambunathan and Singh 1981).

Anti-nutritional Factors

Polyphenolic compounds (commonly referred to as tannins), phytic acid, cyanogenic glucosides, etc. act as nutritional inhibitors in coarse grains. They have been reported to reduce the bio-availability of protein and other nutrients, but, at the same time, polyphenols have also been shown to contribute some degree of resistance or tolerance to bird depredation, pre-harvest germination, and weathering (Hulse et al. 1980). In legumes, in addition, inhibitors of enzymes such as trypsin, chymotrypsin, and amylase, and of flatulence-causing oligosaccharides such as stachyose, raffinose, and verbascose, play important roles. The levels of these anti-nutritional factors have been determined in pigeon-pea and chick-pea whole seed (Singh and Jambunathan 1981; Singh et al. 1982), as shown in table 7. In general, desi chick-pea exhibited higher levels of these factors than kabuli. Genotypes and environments that may affect these levels were not examined in these studies. However, the low levels of these anti-nutritional factors both in pigeon-pea and chick-pea, which would be further reduced or destroyed on cooking, suggest no great need for concern on this score. The levels of these factors and the role of polyphenolic compounds (tannins) in the bio-availability of nutrients assume importance in pigeon-pea in areas where it is consumed without cooking when whole and mature, or as a developing green seed (Jambunathan and Singh 1980).

TABLE 7. The Levels of Anti-nutritional Factors and *in-vitro* Protein Digestibility in Seed Samples of Pigeon-pea and Chick-pea

Component	Pigeon-pea[a]		Chick-pea[b]	
	Range	Mean	Range	Mean
Trypsin inhibitor[c]	5.5–12.1	9.6	8.1–15.7	11.6
Chymotrypsin inhibitor[c]	2.1–3.6	3.0	6.1–8.8	7.7
Amylase inhibitor	23.6–31.0	26.4	5.0–9.7	6.8
Stachyose (%)	0.5–1.0	0.8	0.8–1.9	1.2
Raffinose (%)	0.5–0.9	0.7	0.4–0.6	0.5
Verbascose (%)	0.6–1.1	0.8		
Polyphenols (mg/g sample)	4.3–11.4	6.6	1.9–6.1	3.5
In-vitro digestibility of protein (%)	52.5–62.0	59.2	57.4–74.8	67.9

a. Based on 9 cultivars.
b. Based on 15 cultivars.
c. Units/mg meal.

Milling Characteristics, Cooking Quality, and Consumer Acceptability

A survey carried out in Haryana, Madhya Pradesh, Maharashtra, Rajasthan, and Uttar Pradesh, which together are the major production and processing areas for pigeon-pea and chick-pea in India (Singh and Jambunathan 1980), yielded the following observations.

Pigeon-pea

Owners of 46 large-scale and 130 small-scale dhal mills were interviewed for their opinions and impressions regarding the milling characteristics of various types of pigeon-pea. Some 130 villagers were interviewed in areas where pigeon-pea seed was reported to give higher dhal yields. Although the dhal yield was reported to vary from one mill to another, depending on the processing method used, there appeared to be a general consensus that round seeds of medium-size and greater hardness yield better dhal recovery. Village-level home processing was reported to give lower dhal recoveries than mechanically operated mills. There were variations in recovery depending on the processing technique used. Consumers seemed to prefer local varieties grown in their own fields. There was a wide variation in colour preference because of long-time associations with a particular grain colour. Interestingly, it was observed that taste seemed to have a priority equal to or higher than cooking time.

Chick-pea

As a common practice, farmers consumed local chick-pea cultivars grown on their own farms. Cultivars with light brown testa colour were generally processed into dhal, desi types of medium seed size being preferred. About 60 to 70 per cent were converted into fine flour, which was used in several recipes. Kabuli cultivars were preferred for consumption whole, as were bold-seeded desi types. Consumption of chick-peas in immature fresh form, or as puffed or parched products, was observed to be a common practice.

A survey of traditional food preparations from sorghum and millet was carried out in 171 villages from seven Indian states (Subramanian and Jambunathan 1980). According to the village housewives, the various foods made from sorghum and millet could be classified into the following food types: *roti* (coarse unleavened bread), porridge, gruel, or boiled, steamed, or fried foods.

In India, roti is the most common food prepared from sorghum and pearl millet. Studies were carried out at ICPISAT on the relationship between roti quality and physico-chemical characteristics of sorghum (Subramanian and Jambunathan 1981). The grain characteristics of 45 sorghum and 16 millet genotypes are given in table 8. It was observed that sorghum flour with good dough stickiness produced an acceptable roti. The relationships between the physico-chemical characteristics and roti qualities as evaluated by a panel of tasters were tested using the methods of rank correlation and multiple regression. Results revealed that several flour components complement each other to influence roti quality. Water-soluble flour fraction, amylose, water-soluble protein and sugars appear jointly to influence and contribute to the overall roti characteristics of sorghum. In regard to pearl millet, swelling capacity of flour, water-soluble protein content, amylose, and sugars were found to be related to roti quality. Several other products that are prepared in various regions of Africa are also being evaluated at ICRISAT in co-operation with scientists located in different parts of the world.

Farmers and other consumers in Maharashtra stated that they prefer local sorghum to hybrid sorghum (Subramanian et al., unpublished data). Therefore, it seems important to carry out consumer-acceptability studies on advanced breeding materials before they are considered for large-scale testing and subsequent release. In another study on six families in the Rahuri area (Maharashtra), hybrid and local sorghum flours were supplied to each family for a period of four weeks. Of the six families, four could not differentiate between hybrid and local sorghum. Further studies on larger numbers are needed to verify this observation.

Several physico-chemical characteristics of pigeon-pea and chick-pea were determined (table 9) to see whether any of them could be used as a screening index for evaluating the cooking quality and cooking time of these pulses. Important physico-chemical characteristics that showed strong relationships with cooking time included the

TABLE 8. Physico-Chemical Characteristics and Roti Quality of Sorghum[a] and Pearl Millet[b] Grain

Factors considered	Sorghum		Pearl millet	
	Range	Mean	Range	Mean
Physical characteristics:				
100-grain weight (g)	2.3–5.5	3.8	0.5–1.0	0.75
Grain hardness (kg)/kernel[c]	3.0–11.8	6.7	1.9–3.2	2.3
Swelling capacity (final volume/initial volume):				
Grain	1.4–1.9	1.6	1.6–2.3	2.0
Flour	5.4–8.0	6.5	4.2–6.0	5.0
WSFF[d] (mg/100 g flour)	19.4–35.4	26.4	22.6–31.9	27.9
Chemical characteristics (% in whole grain):				
Protein	8.0–14.1	10.6	10.8–17.4	13.7
Water-soluble protein	0.30–0.90	0.56	1.02–1.30	1.15
Starch	62.6–74.3	58.7	63.1–70.5	66.9
Amylose	21.2–30.2	27.2	21.9–27.4	24.6
Water-soluble amylose	4.8–12.7	8.5	3.6–7.6	5.0
Soluble sugars	0.7–1.6	1.0	2.0–2.6	2.4
Reducing sugars	0.05–0.43	0.11	0.10–0.26	0.17
Fat	2.3–4.7	3.3	4.1–5.7	4.7
Ash	1.3–2.2	1.6	1.8–2.4	2.1
Tasters' panel evaluation of roti (excellent: 4; poor: 1):				
Colour and appearance	1.0–3.8	2.5	1.6–3.6	2.6
Texture	1.2–3.8	2.5	1.6–3.8	2.8
Flavour	1.7–3.4	2.6	1.8–3.2	2.6
Taste	1.0–3.3	2.6	1.6–3.0	2.5
General acceptability	1.5–3.5	2.5	1.2–3.0	2.5

[a] Based on 46 cultivars.
[b] Based on 16 cultivars.
[c] Breaking force needed (Hardness tester—Kiya Seisakusho Ltd., Tokyo, Japan).
[d] Water-soluble flour fraction.

mount of solids dispersed in cooking water, nitrogen content in the solids dispersed, water absorption of dhal, texture as determined in the Instron Food Testing Instrument (Model 1140 Highwycombe, Berkshire, United Kingdom), phytic acid, and minerals such as calcium and magnesium. Thus texture, solids dispersed, water absorption, and

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