Grain Quality and Biochemistry
Progress Report- 8/88

Pigeonpea

Report of Work

January 1987 — December 1988

ICRISAT

International Crops Research Institute for the Semi-Arid Tropics
Patancheru, Andhra Pradesh 502 324, India

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FOREWORD

This report on the work done during January 1987-December 1988 has been prepared to share the information with scientists who have an interest in grain quality and biochemistry aspects of pigeonpea.

This is not an official publication of ICRISAT and should not be cited.

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R. Jambunathan

Project No. : BN-102 (87) IC

Project Title : **Study of grain and food quality parameters of pigeonpea**

Objectives and Scope

a. Monitor grain quality and cooking quality of advanced breeding lines.

b. Investigate the role of physicochemical properties involved in determining the cooking time of whole seed and dhal.

c. Evaluate the protein quality by rat feeding trials and study the factors that affect protein digestibility.

d. Explore the possibility of preparing some new food products of pigeonpea and study their consumer acceptance and nutritional quality.

f. Develop a suitable procedure for dehulling quality and study the relationship between grain characteristics and dehullintg quality of different genotypes.

: Grain quality, cooking quality, physicochemical properties, consumer acceptance, chemical composition, nutritional quality.

Contents

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1. New Food Uses : Starch Properties and Noodle Quality

Efforts are needed to explore new food uses for pigeonpea, such as starch-based food products, noodles, and fermented food products (e.g.), to enhance its utilization in some Southeast Asian countries. With this objective in view, the physicochemical properties of pigeonpea starch and its noodle quality were studied, and the results were compared with those obtained with mung bean starch to examine the suitability of pigeonpea starch for making acceptable noodles. For this purpose, one cultivar (C 11) of pigeonpea and one cultivar (PS 16) of mung bean were grown at ICRISAT Center, Patancheru, India during the rainy season 1987. The harvested seed lots were cleaned, soaked for 4 hr at room temperature (25 ± 1°C), and dried in the oven at 55°C). They were decorticated, using the Tangential Abrasive Dehulling Device (TADD) to prepare dhal.

1.1 Chemical analysis

For chemical analysis, about 200 g each of whole seed and dhal samples of pigeonpea and mung bean were ground in a Udy cyclone mill, using the 0.4 mm screen. Whole seed and dhal (decorticated dry split cotyledons) samples of pigeonpea and mung bean were analyzed as described previously for protein (Singh and Jambunathan, 1981), fat, ash, crude fiber (AOAC 1975) and soluble sugars and starch (Singh et. al. 1980). Isolated starch samples were also analyzed for starch, protein, ash, and crude fiber according to methods cited above. Amylose content in the isolated starch sample was determined using the method of Williams et al. (1958).

The concentration of various chemical constituents in the whole seed and dhal samples of pigeonpea and mung bean are shown in Table 1. Soluble

sugars, fat, and ash, contents of pigeonpea whole seed and dhal were noticeably higher than those of the mung bean (Table 1). Protein content of pigeonpea was considerably lower than that of mung bean, whereas no large differences in starch content were observed. Crude fiber contents of both whole seed and dhal of pigeonpea were remarkably higher than in mung bean and this might have interferred in starch extraction as disussed below.

1.2 Isolation of starch

Starch was isolated from the whole seed and dhal samples, using the method of Schoch and Maywald (1968) with some minor modifications as follows: legume samples were steeped in water overnight, and washed and ground in a waring blender at low speed for 2 min. The slurry was filtered through a cloth bag (about 80 mesh) and then through a standard sieve (200 mesh). The filtrate was kept aside for about 4-6 hr to sediment the starch. For increased starch yield, the starch was reslurried in water and sedimented 2-3 times or until the water was clear. The recovered starch was then dried in a hot air oven at 50°C. The starch yield was expressed as the percentage recovery of the total of starch that was determined in the sample.

The starch yields from both whole seed and dhal samples of mung bean were higher than those of the pigeonpea (Table 2). Differences in whole seed samples were more pronounced, which could be to differences in their fiber contents. However, the starch yields from mung bean and pigeonpea were considerably higher than from other legumes (Schoch and Maywald, 1968). But the results of present study indicated that starch was more extractable from mung bean than from pigeonpea.

Chemical analysis of the isolated starches showed that the starch fraction contained 0.10-0.18% protein, 0.03-0.09% ash, and 0.0-0.11% crude fiber, indicating high purity of the starch fraction (Table 2). No large differences in the amylose content of pigeonpea and mung bean starches were observed. However, amylose contents of these legumes are considerably higher than those of other legumes.

1.3 Microscopic analysis of starch

The size and shape of isolated starch granules were examined, using a light microscope. Starch granules were stained with 0.1% iodine solution, prepared by mixing, 100 mg iodine in 100 mL of 0.1% potassium iodide solution. Starch granule sizes were determined with an eyepiece micrometer.

Gelatinization temperature of starch was determined using a light microscope, congo-red (0.2%) was used as a stain. The aqueous solution of starch was heated, using a mini block heater, and samples were taken from 60°C onwards at 1°C intervals until the gelatinization temperature was reached. Starch granules were stained at initial, midpoint (50% stained), and final (90% stained). The temperature at which 90% of the starch granules were stained was recorded as the gelatinization temperature.

Microscopic examination (600 X) showed that most pigeonpea and mung bean starch granules had irregular shapes, which varied from oval to round to bean-shaped (Fig. 1). A large variability existed in the starch granule sizes of both pigeonpea and mung bean (Table 3). In general, pigeonpea starch granules were slightly bigger than the mung bean starch granules. Mung bean starch granule size varied from 9.5 to 47.5 u with mean being 21.7 u and pigeonpea between 9.5 and 55.1 u with mean being 24.7 u. Of the

various grain legumes, starch granule size has been reported to be smallest (range 12-32 u) for mung bean and highest (range 20-48 u) for faba bean.

Gelatinization temperature is associated with the loss of birefringence characteristics of starch. The gelatinization temperature of pigeonpea starch (76°C) was slightly higher than that of mung bean starch (72°C), as shown in Table 4. The ranges in gelatinization temperature of pigeonpea starches (65-71-76°C) and mung bean starches (61-65-72°C) were obtained.

1.4 Gel strength and syneresis

Gel strength was measured using a compression cell (0.-5 kg full scale) in an Instron food testing machine (Model 1140, High Wycombe, Derkshire, UK). Thirty-five mL of 6% starch solution, previously heated at 95°C for 10 min, was poured into a round moisture dish (5 cm diameter) and stored at room temperature for 12 hr. Uniformly polymerized round starch gel slab of 1 cm thickness were removed from the moisture dishes and compression forces were measured by pressing the gel slab between two flat plates which were considerably larger in size than the sample to prevent puncture of the gel. Samples were compressed to 50% of the crosshead speed.

The degree of syneresis of starch gels was determined by measuring the volume of water (mL) separated from the gel after storage at 4°C for 12 hr. The gel consistencies of the 6% starch gels of pigeonpea and mung bean were measured as follows: The isolated starch (120 mg) was heated in 2 ml distilled water in 15 x 150 mm test tube for 5 min at 95°C. After standing for 30 min at room temperature (25 ± 1°C), test tubes were placed horizontally for 30 min on a graph sheet and gel spread (length) measured.

The results indicated that the degree of syneresis of pigeonpea starch gel was higher than that of mung bean (Table 4). We also studied degree of syneresis at different concentrations and observed that the degree of syneresis increased as the concentration of starch gel decreased. On the other hand the gel strength of pigeonpea starch was lower than that of mung bean, but no large differences in their gel consistency values were observed. The lower gel strength has been attributed to its low iodine affinity value, i.e., lower amylose content. But in the present study, no noticeable differences in amylose content of mung bean and pigeonpea starches were observed (Table 2), implying that differences in the gel strength of these two legumes may be due to other factors than to their amylose content alone.

1.5 Swelling power and solubility determination

Isolated starch (200 mg) was used for swelling power and solubility determinations from 60-90°C at 10°C intervals, as per the method of Leach et al. (1959).

The starch granules are held together by hydrogen-bonding forces in the form of crystalline bundles, called micelles. When an aqueous suspension of starch granules is heated, these structures are hydrated and eventually swelling takes place. The swelling power of pigeonpea and mung bean starches at different temperature is presented in Fig. 2. Table 5 shows the swelling power and solubility percent of mung bean and pigeonpea. The patterns of swelling power of mung bean and pigeonpea starches showed marked differences, particularly at lower temperatures (Fig. 2). Mung bean starch swelled rapidly at relatively lower temperature than pigeonpea. However the swelling powers of pigeonpea and mung bean starches were comparable at higher temperatures. From the data, it appeared that both

mung bean and pigeonpea starches were exemplified by a two-stage swelling process, i.e., the initial swelling followed by a period of rapid rate of swelling (Fig. 2). This behaviour was attributable to two sets of bonding forces with relaxation at different temperature levels, a weak association relaxing at 65-75°C, and a second stronger relaxing at 85-95°C. On the other hand, solubility of starches of these two legumes did not show large differences (Fig. 2).

1.6 Viscosity measurements

The Brabender viscosity patterns of starches are primarily determined by (1) the extent of swelling of the starch granules; and (2) the resistance of the swollen granules to dissolution by heat or fragmentation by shear. Having observed differences in the swelling power of pigeonpea and mung bean starches, their viscosity patterns at different temperatures were examined. The Brabender viscosity patterns of 6% starch pastes of pigeonpea and mung bean gave no pasting peak during heating at 95°c. Both showed a stable graph, indicating that there was no breakdown of the hot paste. Such a pattern is similar to most of the legume starch pastes, and it could be classified into type C of Schoch's classification (Schoch and Maywald, 1968). No values were reported for peak viscosity because no distinct peak was obtained with the legume starches as with wheat starch. Marked differences in viscosity patterns of pigeonpea and mung bean starches were not observed, however, at different temperatures (Table 6). The viscosity patterns of these legumes appeared to be related to their swelling power. Interestingly, the viscosity of pigeonpea starch at lower temperatures (35°C and 50°C) was remarkably lower than that of the mung bean starch. As mentioned above, the swelling power of pigeonpea starch at lower temperatures was also noticeably lower than mung bean starch. The

extent of increase in viscosity on cooling to 50°C reflected a retrogradation tendency in the starch molecules. Pigeonpea starch showed a much lower set-back value than mung bean starch (Table 6).

1.7 Noodle preparation

Soft and hard noodles of mung bean and pigeonpea starches were prepared, as per Singh et al (1989), with the following minor modifications : for preparing soft noodles, dry starch and water (1:7 w/v) were boiled for 5 min and starch gel thus obtained was extruded into cold water, using a locally available extruder with a hole opening of about 2 mm diameter. Soft transparent noodles 15-20 cm long, with moisture content of 60-65%, were obtained. For preparing hard noodles, dried starch and cooked starch (95:5 w/w) were mixed in water in the ratio of 1:7 (w/v) and extruded into boiling water. Noodles were separated, kept at 5°C in the refrigerator overnight, and sun dried. Freshly cooked noodles were evaluated by 10 trained panel members for color, texture, clarity, uniform appearance, and general acceptability, using a score of 4 for excellent and 1 for poor quality. These sensory properties were explained to the panel members before the sensory evaluation.

The noodle quality of both whole seed and dhal of pigeonpea and mung bean was examined by sensory evaluation. Sensory properties, such as color, texture, clarity, and general acceptability, were evaluated, using soft and hard noodles, and the results are presented in Table 7. Soft noodles of pigeonpea and mung bean starch are shown in Fig. 3.

Starch extruded from whole seed and dhal samples of these legumes showed noticeable differences in their noodle qualities (Table 7). The whole-seed starch isolated from pigeonpea produced noodles with poor to fair

quality, with an average score of 1.9 on general acceptability, whereas the noodles of whole-seed starches of mung bean were rated as fair to good with an average score of 2.8 (Table 7). The scores for noodle clarity and color from whole-seed starch of pigeonpea were lower than those of the mung bean. On the other hand, dhal starch of pigeonpea produced noodles with better quality than that of mung bean, as revealed by various sensory properties (Table 7) and noodle color (Fig. 3). This was due to the brighter color of pigeonpea dhal starch as no pigments might have been extracted in the case of pigeonpea dhal starch. No marked differences were observed in the quality of hard noodle of mung bean and pigeonpea dhal starches (Table 7). These results indicate that in the case of whole seed starch, noodle quality was better for mung bean than for pigeonpea whereas the reverse was true, except for texture, for dhal starch (Table 7). Quality of hard noodle from dhal starch of pigeonpea and mung bean was comparable.

The starch yields from both whole seed and dhal samples of mung bean were higher than those of pigeonpea indicating that starch was more extractable from mung bean than from pigeonpea. Amylose values of mung bean and pigeonpea starch were comparable. Although there were differences in swelling power of mung bean and pigeonpea starches at lower temperatures, both legumes showed restricted swelling and a C-type Brabender viscosity curve; they thus possessed desirable starch qualities for noodle manufacture. Sensory tests also indicated that from whole seed starch, the noodle quality was better in mung bean than in pigeonpea. But starch from pigeonpea dhal was as good for noodle preparation as that from mung bean dhal or even better, which was due to bright color of pigeonpea dhal starch. Although the present results were based on analysis of one cultivar each of pigeonpea and mung bean additional studies using cultivars

with variable seed coat color of these legumes would be useful to know the influence of seed coat pigments on starch color and noodle quality. The effect of fiber components on starch yields of mung bean and pigeonpea also needs to be investigated. As pigeonpea dhal starch was brighter than mung bean dhal starch, the extraction of pigments along with the starch in the case of mung bean needs to be investigated in detail in view of the large scale utilization of mung bean starch for making transparent noodle in several Asian countries.

1.8 Tempeh, a fermented product

Tempeh, traditionally prepared from soybean is an important food in Indonesia. Pigeonpea utilization in tempeh in Indonesia has often been suggested. We standardized the procedure of tempeh preparation in our laboratory. The procedure which is commonly used in Indonesia was followed with minor modifictions. We prepared pigeonpea tempeh, using the culture obtained from Indonesia, and compared it with soybean tempeh prepared in a similar way. Organoleptic properties of pigeonpea and soybean tempeh are summarized in Table 8. The organoleptic properties such as color, taste, texture, and flavour in tempeh of pigeonpea and soybean were similar, suggesting that pigeonpea can substitute soybean in tempeh preparation. Further, we compared different temperatures and durations of incubation for fermentation and found that fermentation could be satisfactorily carried cut at 30°C for 24 h. Preliminary studies also indicated that pigeonpea cultivar C 11 (brown seed coat) required more time to ferment for tempeh preparation compared with cultivar Nylon (white seed coat). We also observed that addition of salt before fermentation delayed fermentation.

2. Cooking Quality

2.1 Cooking quality analysis of white pigeonpeas

Keeping in mind the utilization of pigeonpea is similar to cowpea in some African countries, it was felt desirable to evaluate available germplasm accessions having white seed coat color and originating from different countries for their cooking quality characteristics. We could analyze 430 such accessions during this year. A detailed report on this aspect has been prepared separately (Progress Report 9/88). One Hundred seed mass (g) of these accessions varied from 6.6 to 22.1 g showing a large variation. On the other hand, variation in the seed coat content of these genotypes was small as it ranged between 8.6 to 17.4. Cooking time of whole seed of these genotypes ranged between 52 min and 96 min indicating a large variation. However, cooking time of overnight distilled water soaked samples of some of these accessions varied from 16 min to 30 min. On an average, soaking treatment brought about one third reduction in cooking time of these genotypes and this showed a beneficial effect of soaking on cooking time.

2.2 Relationship between cooking time and physicochemical factors

Correlation coefficients between various cooking quality characteristics of 57 germplasm accessions are given in Table 9. There was no correlation between 100-seed mass and cooking time of both unsoaked and soaked samples. Interestingly, seed coat content was not correlated with cooking time implying that seed coat may not influence the cooking time. There was a significant and positive correlation, although of low magnitude, between the cooking times of soaked and unsoaked samples. This might suggest that relative differences in hard and soft cooking accessions may be maintained even after soaking treatment. However, analyses of more number of white

pigeonpeas as said above have been compiled in a separate progress report of our department.

2.3 Evaluation of released and advanced genotypes'

We continue to monitor the grain and food quality of genotypes developed by ICRISAT and during this period, 16 genotypes including checks were evaluated for their cooking quality and organoleptic properties of dhal. As shown in Table 10, cooking time of dhal samples of these genotypes ranged between 21.0 min for ICPL 8357 and 29.0 min for HPL 40, a high protein genotype. For organoleptic properties, dhal samples of genotypes were boiled for 25 min without adding salt or any other gradient and evaluated by 10 sensory panel members for color, texture, flavour, taste, and general acceptability. There were some differences among the genotypes with respect to taste, color, and texture. General acceptability score was highest (3.2) for ICPL 8398, ICPL 87, ICP 8863, BDN 1, and C 11, and lowest 2.0 for ICPL 4 (Table 10).

In addition, we evaluated 18 genotypes developed by ICRISAT and grown at CARDI, Belize. These genotypes were studied for various cooking quality parameters including dehulling quality (dhal yield) and the results of this study are summarised in Table 11. Cooking time of whole seed of these genotypes varied from 52 min to 76 min with a mean of 61 min whereas cooking time of the dhal samples of these genotypes varied from 22 min to 43 min. Dehulling quality (dhal yield) of these genotypes did not show large variation as dhal yield ranged between 78.8 and 83.2%.

2.4 Effect of location on cooking time and protein content

Some low, medium, high protein genotypes were grown at different locations in India as shown in Table 12 Seed samples of these genotpes

were obtained from collaborators and analyzed for protein content and cooking time. By and large, high protein genotypes maintained their protein content when grown at different locations. Cooking time of whole seed of these genotypes showed considerable differences. But large differences in cooking time were observed when the results of low and high protein genotypes were compared.

3. Nutritional quality evaluation of high protein genotypes

3.1 Chemical analysis

The experimental seed material for the present study consisted of two high-protein (HP) genotypes (HPL 8 and HPL 40) and two normal-protein (NP) genotypes (C 11 and ICPL 211). C 11 is a released commercial variety. These genotypes were grown at ICRISAT Center, Patancheru, India, during the rainy season, 1986. Whole-seed samples were decorticated to prepare dhal (decorticated dry split cotyledons) by using Prairie Regional Laboratory (PRL) mill. About one kilogram each of whole seed and dhal samples were cooked for 15 min at 15 lb pressure in a pressure cooker. After cooking, the whole content, including the broth, was dried in the oven at 50°C. Raw and cooked samples were ground in a Udy cyclone mill to pass through a 0.4 mm screen.

Nitrogen content in pigeonpea samples was determined, using the Technicon auto analyzer (Singh and Jambunathan 1981), and nitrogen values were converted into protein by multiplying by a factor of 6.25. For amino acid analysis and protein fractionation, finely ground samples were defatted in a Soxhlet apparatus, using n-hexane. Previously published methods were used for the determination of ash, fat, and crude fiber (AOAC 1975) and soluble sugars and starch (Singh and Jambunathan 1980).

The protein content of dhal of the HP genotypes (HPL 8 and HPL 40) is significantly higher (25%) than the NP genotypes (ICPL 11 and ICPl 211) as shown in Table 12. The present study show that the genotypic differences are quite large, although the possibility of small environmental effects on the protein content of these genotypes could not be ruled out. The protein content of some HP genotypes of pigeonpea, including HPL 40, has been reported to vary from 27.0 to 29.8%. Expectedly, the starch content of HP genotypes was lower than the others and a similar trend was observed for fat content. On the other hand, soluble sugars, ash and crude fiber showed variable results among these genotypes (Table 13).

From the consumers' point of view, small-seeded pigeonpeas are not preferred. One-hundred-seed mass of HP genotype HPL 8 was comparable with those of the NP genotypes (Table 13). However, 100-seed mass of HPL 40 was slightly lower, and this might have been due to environmental effects. The 100-seed mass of this genotype has been reported similar to those of the other genotypes of pigeonpea evaluated under identical conditions. Also, values for the seed coat percentage of HP genotypes did not differ significantly, suggesting that these genotypes might be acceptable for dehulling in terms of dhal yield.

3.2 Seed protein fractionation and amino acid analysis

Seed proteins were fractionated into albumin, globulin, glutelin and prolamin by successive extractions with different solvents as described earlier (Singh and Jambunathan 1982). Defatted flour samples were successively extracted with 0.5 M sodium chloride solution in 0.01 M phosphate buffer (pH 7.0), 0.1 N sodium hydroxide and 70% ethanol to separate total protein into albumin and globulin, glutelin and prolamin fractions, respectively.

Considerable differences were observed in the concentrations of the major protein fractions, globulin and glutelin, of these genotypes (Table 14). The globulin fraction was noticeably higher in HP genotypes than in NP genotypes, and the reverse was true for the glutelin fraction. The storage proteins, globulins, constitute the major proportion of the legume seed proteins. Since these proteins are deficient in sulphur containing amino acids, the limitations of these proteins in the nutrition of humans and other monogastric animals are well known. The higher levels of sulphur containing amino acids in the glutelin than in the globulin fraction of pigeonpea have led to the suggestion that cultivars with a higher ratio of glutelin to globulin should be identified to improve their seed protein quality (Singh and Jambunathan 1982). These small relative changes in protein fractions of these genotypes did not result, however, in changes in the limiting essential amino acids, methionine and cystine and other essential and non essential amino acids. Although tryptophan is an essential amino acid of pigeonea, and nutritionally important, this amino acid was not determined in the present study as it was destroyed during refluxing in 6 N HCl. Like other plant proteins, amino acid composition serves as a first approximation of the protein quality of pigeonpea proteins. No marked differences were observed in sulphur containing amino acids of the HP and NP genotypes.

3.3 Trypsin and chymotrypsin inhibitors

The trypsin inhibitor activity (TIA) was assayed according to Kakade et al (1969). Trypsin inhibitor was extracted by shaking 200 mg of defatted material with 10 ml of 0.1 M phosphate buffer (pH 7.6) at room temperature for 1 hr. Extracts were assayed for TIA. Chymotrypsin inhibitor activity (CIA) was assayed to according to Kakade et al (1970). Chymotrypsin

inhibitor was extracted as described above, except that 0.1 M borate buffer (pH 7.6) was used.

In common with other grain legumes, pigeonpea seeds contain considerable amount of protease inhibitors. Trypsin and chymotrypsin inhibitors of raw and cooked samples of the HP and NP genotypes are shown in Table 16 Trypsin inhibitor activity (TIA) did not reveal marked differences in the HP and NP genotypes, although differences among the genotypes were significant ($P<0.01$). TIA was remarkably reduced as a result of cooking in all the genotypes. Chymotrypsin inhibitor activity (CIA) was slightly higher in the raw samples of HP genotypes than in that of NP genotypes. However, CIA was not detected in cooked samples, indicating that CIA was completely destroyed in the heat treatment. But this did not happen in the case of TIA.

3.4 Biological evaluation

Protein digestibility is of increasing interest in grain legumes in general and pigeonpea in particular. True protein digestibility (TD), biological value (BV), net protein utilization (NPU) and utilizable protein (UP) were determined, by conducting rat feeding experiments using raw and cooked whole seed and dhal samples of these genotypes. Groups of five Winstar male rats, weighing about 70 g, were used in these experiments. Each rat was daily fed a 10 g diet (dry weight basis) containing 150 mg nitrogen. At the end of the 5 days of feeding period, unconsumed diet weight was recorded and total nitrogen intake calculated. The remaining procedures were followed and calculation of TD, BV, NPU and UP values made according to Eggum (1973).

The results of these experiments are summarised in Tables 17 and 18. True protein digestibility (TD) significantly ($P < 0.01$)) increased with cooking and the effect was more pronounced in whole seed than in dhal samples (Table 17 and 18). Interestingly, biological value (BV) of the cooked sample decreased in both whole seed and dhal, whereas net protein utilization (NPU) of the cooked samples increased; this may be due to an increase in the protein digestibility. A decrease in BV of cooked samples of both whole seed and dhal might be attributable to heat treatment, which causes considerable nutritional damage to methionine, the most important amino acid of grain legumes.

A comparison of TD of raw samples of whole seed and dhal samples of these genotypes indicated large differences. The average TD was nearly 60% for whole seed (Table 17), whereas it increased to over 70% in dhal samples (Table 18). The reduced TD of whole seed may be due to higher polyphenols and fiber contents as majority of these compounds are concentrated in the seed coat. Polyphenols decrease protein digestibility in animals and humans, probably by making protein partially unavailable or by inhibiting digestive enzymes and increasing fecal nitrogen. Polyphenols may not have a great nutritional implication as they are removed by the processing of pigeonpea.

Although TD, BV, and NPU values have shown some differences among these genotypes, no noticeable difference in these protein quality attributes were observed among the HP and NP genotypes. More importantly, the values for utilizable protein (UP) were considerably higher in the HP genotypes than in the NP genotypes. Higher UP values for the HP genotypes are attributed to their higher protein content. This indicated that the HP genotypes are nutritionally better than the NP genotypes as the former

contain more utilizable protein.

Our results show that the levels of various nutritional attributes of the HP and NP genotypes are quite comparable, and that it is possible to improve pigeonpea protein content and its quality by breeding. Further, the HP genotypes may be preferred from the nutritional point of view over the NP genotypes as, per se, they would provide more utilizable protein and sulphur containing amino acids. To enhance the nutritive value, utilization, and productivity of the crop, the devleopment of high-protein cultivars with desirable agronomic traits may be emphasied in the breeding programs

4. Effect of cooking on protein digestibility and amino acids

Pigeonpea generally has a lower protein digestibility than other grain legumes, even after cooking. We examined the effect of cooking on protein digestibility, biological value, and meet protein utilization by conducting rat feeding trials on raw and cooked whole seed and dhal samples of C 11. The results of this study are summarised in Table 19.

Protein digestibility significantly ($P < 0.01$) increased with cooking and the effect was more pronounced in whole seed than dhal samples (Table 19). Interestingly, biological values of the utilization of the cooked samples increased and this may be due to an increase in the protein digestibility.

Amino acid composition of raw and cooked whole seed and dhal samples of C 11 is presented in Table 20. This study was conducted to determine the effect of cooking on amino acid contents of pigeonpea. It is emphasized that cooking water was discarded after boiling the samples. No

remarkable changes in the amino acids of pigeonpea were observed as a result of cooking. A slight reduction in lysine content was noticed whereas methionine and cystine, limiting essential amino acids of pigeonpea, did not show any change due to cooking (Table 20).

5. Effect of seed polyphenols on protein digestibility

Grain legume polyphenols have been reported to influence the protein digestibility. Earlier we have observed that majority of the polyphenols are concentrated in the seed coat and also that polyphenols are highly associated with the seed coat color. In other words, it can be predicted that pigeonpea genotypes with brown seed coat would contain more polyphenols than those of the genotypes having light/white seed coat color. In view of this, we conducted rat feeding trials using cooked whole seed and dhal samples of C 11 (brown seed coat) and Nylon (white seed coat) in order to study the effect of polyphenols on protein digestibility and the results are summarised in Table 21. The results of this study indicated that polyphenols reduced the protein digestibility as the digestibility of C 11 was lower than the Nylon as former contained higher amounts of polyphenol. This was further substantiated as these differences disappeared when the dhal samples of these cultivars were compared. This showed that in case of dhal sample, no noticeable intereference of polyphenonl in protein digestibility were observed. Biological value and net protein utilization of C 11 and Nylon showed noticeable differences in whole seed but not in dhal sample (Table 21). There were large differences in the polyphenols of whole seed and dhal samples of these two cultivars as shown in Table 22.

6. Vegetable pigeonpeas

We continued to study the grain quality of vegetable pigeonpeas. There is usually a 3-4 days gap between the date of harvesting of green pods for vegetable purpose and the time of consumption of their green seeds as a vegetable. In order to assess the changes in quality traits during the short storage period, we studied the effect of storage on cooking quality of vegetable pigeonpeas. Green pods were harvested and stored at 5°C and 25°C separately. After storage, the pods were shelled and the moisture content, cooking time and texture (hardness) of the green seeds were determined. The results of this study are summarised in Table 23. Texture was determined in Instron food testing machine. Storage at room temperature increased the cooking time of green seeds and this observation was substantiated by the results on texture (hardness). However, it was observed that the storage at low temperature did not cause any noticeable changes in cooking quality for up to three days of storage (Table 23).

7. Dehulling quality

Earlier, we have observed that the procedure of Tangential Abrasive Dehulling Device (TADD) could be used for studying dehulling quality of pigeonpea genotypes. Also, our village-level and dhal mill surveys have indicated some pretreatments, e.g. moistening the seed with water or oil are performed before dehulling pigeonpea in a dhal mill. Effect of seed treatment with different salt solutions on dhal yield was studied using TADD. Seeds of C 11 were treated with sodium chloride, sodium carbonate, sodium bicarbonate solutions, oil and water. Seeds were dried in the oven at 50°C overnight and dehulled in TADD. As shown in the Table 24, there was no noticeable effect of pretreatments on the dhal yield. However, these are the results of a preliminary study and additional efforts in this

direction will be useful.

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Figure 1 : Size and shape of starch granules of mung bean (a) and pigeonpea (b)

a

b

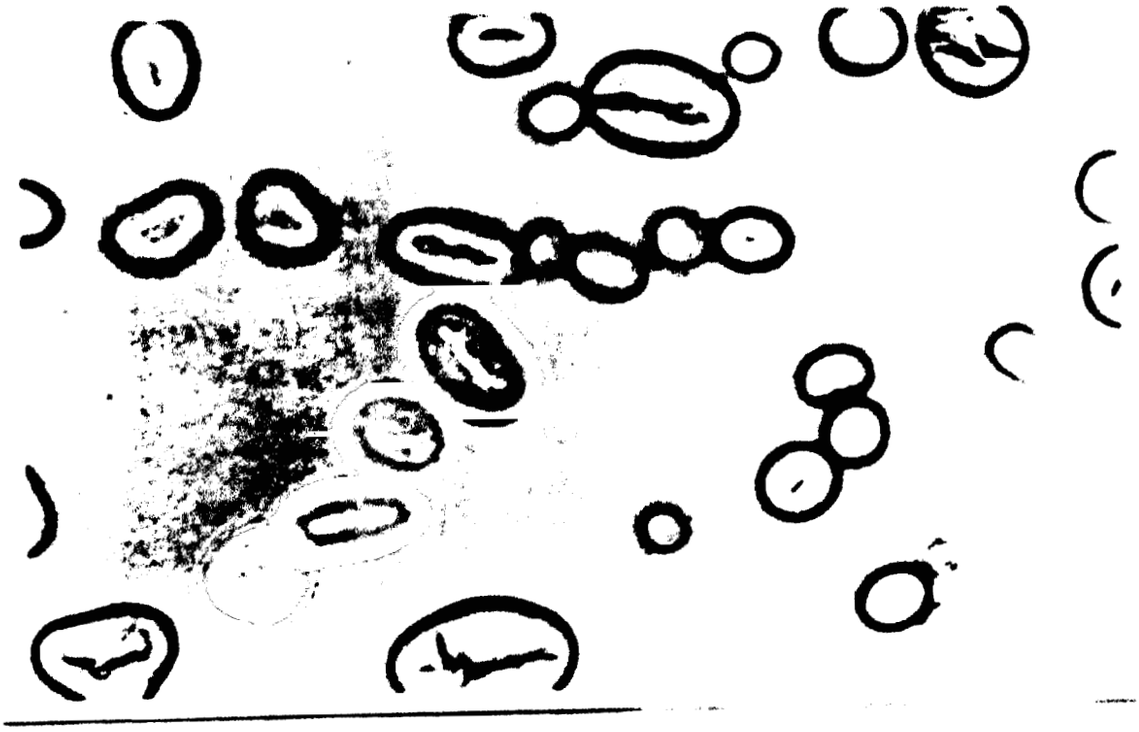

Figure 2 : Swelling power and solubility patterns of mung bean and pigeonpea starches at different temperatures

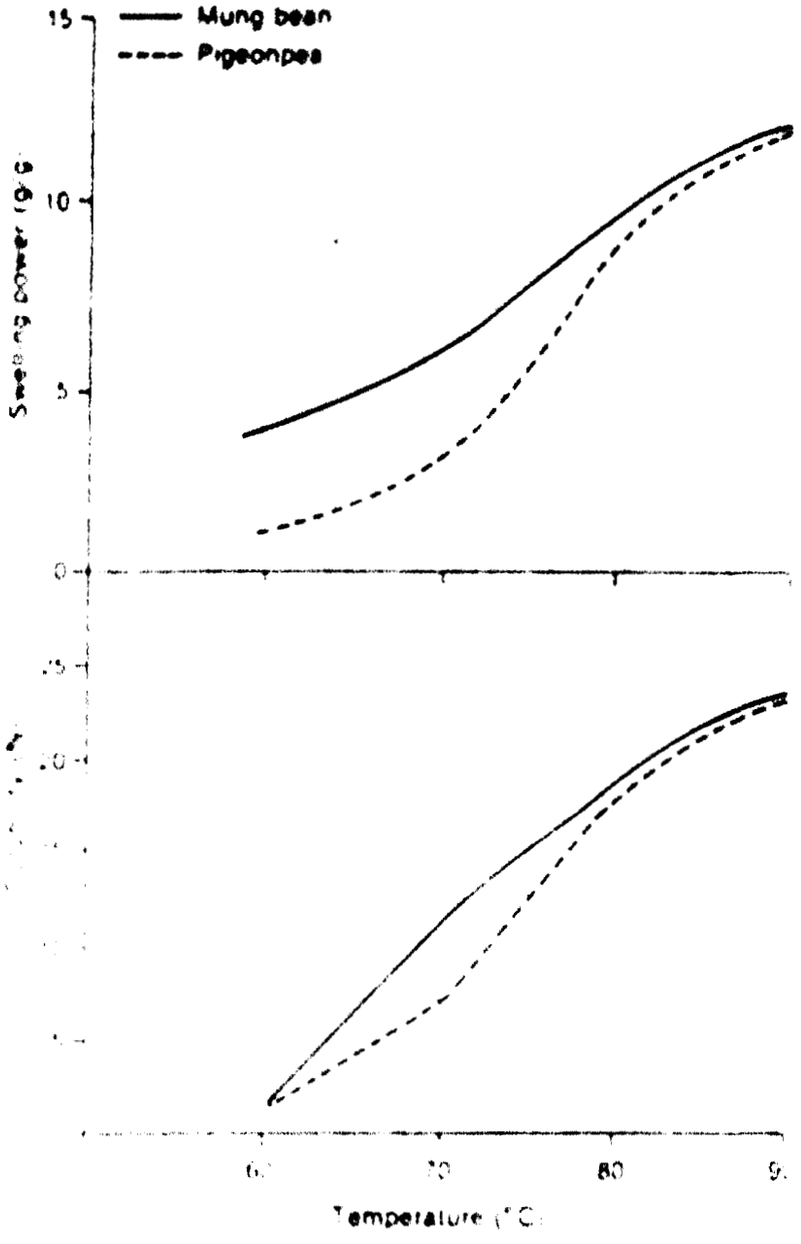

Figure 3 : Starch noodles of whole seed and dhal samples of mung bean and pigeonpea

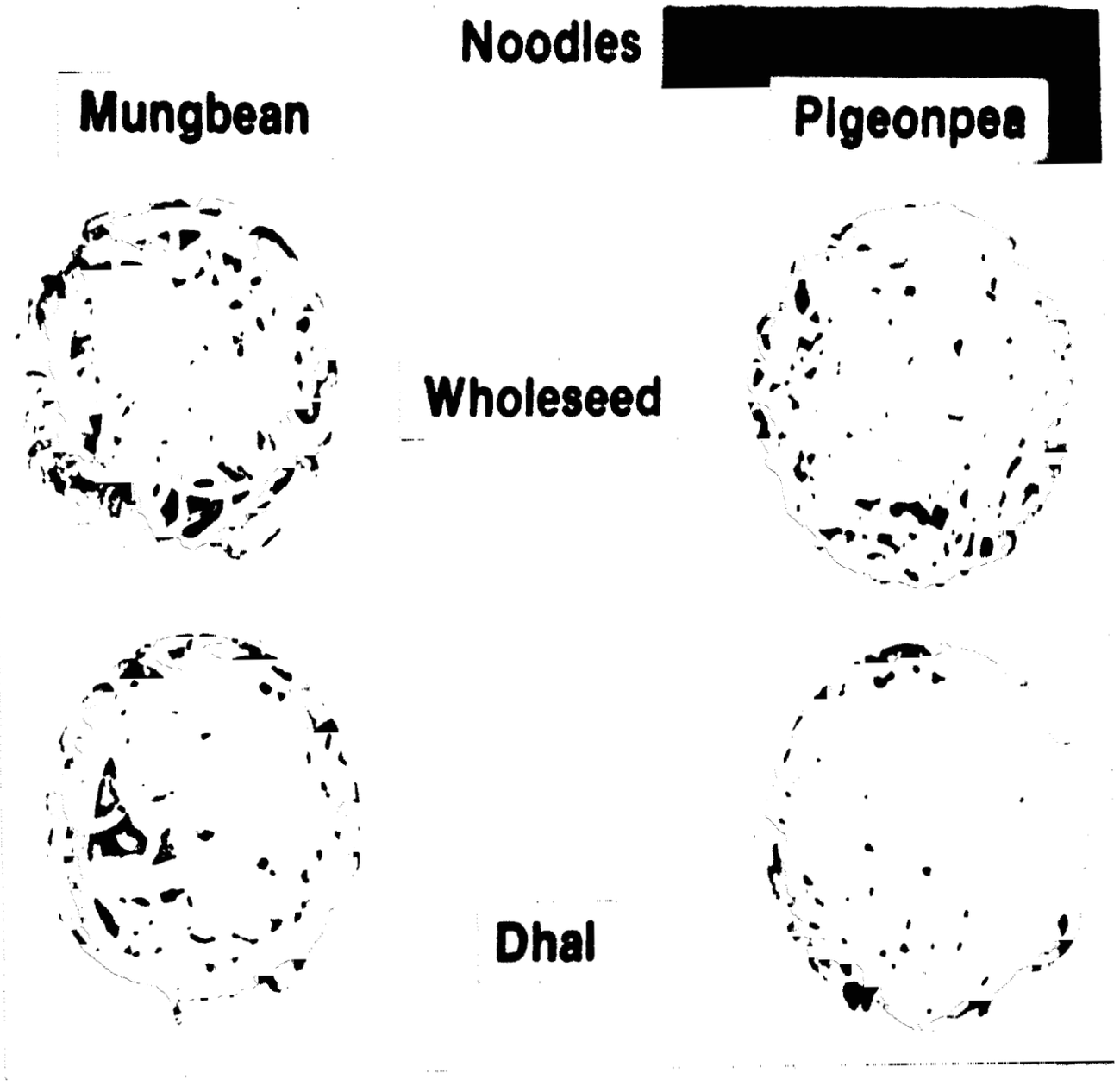

Table 1. Chemical composition of whole seed and dhal of pigeonpea (cultivar C 11) and mung bean (cultivar PS 16)[1].

Crop	Seed color	100-seed mass (g)	Seed coat (%)	Protein (%)	Starch (%)	Soluble sugars (%)	Fat (%)	Ash (%)	Crude fiber (%)
Whole seed									
Pigeonpea	Light brown	11.0	13.0	20.9	55.3	6.1	1.8	4.6	7.7
Mung bean	Green	4.5	10.6	25.8	56.3	5.2	1.3	3.8	4.5
SE		±0.38	±0.54	±0.06	±0.36	±0.04	±0.03	±0.03	±0.06
Dhal									
Pigeonpea	Light yellow	-	-	23.5	60.4	6.4	1.9	4.9	1.4
Mung bean	Light yellow	-	-	26.6	62.3	4.1	1.2	3.6	0.8
SE		-	-	±0.16	±0.74	±0.04	±0.03	±0.04	±0.03

1. Means of two determinations, expressed on moisture-free basis.

Table 2. Chemical composition of isolated starches of whole seed and dhal of pigeonpea (cv C 11) and mung bean (cv PS 16)[1]

Crop	(%) of starch extracted	Isolated starch fraction[2]				
		Starch (%)	Amylose (%)	Protein (%)	Ash (%)	Crude fiber (%)
Whole seed						
Pigeonpea	49.3	92.0	46.9	0.18	0.04	0.08
Mung bean	59.3	90.9	47.0	0.14	0.09	0.11
SE	±3.79	±1.04	±1.23	±0.04	±0.02	±0.02
Dhal						
Pigeonpea	71.2	93.6	49.0	0.17	0.03	0.0
Mung bean	78.9	94.3	50.3	0.10	0.06	0.05
SE	±3.38	±1.20	±1.04	±0.03	±0.02	±0.02

1. Means of two determinations, expressed on moisture-free basis.

2. Determined in isolated starch fraction.

Table 3. Shape and sizes of pigeonpea and mung bean starches.

Crop	Shape	Size (u)[1]	
Pigeonpea	Irregular (oval/round/bean-shaped)	Range	9.5–55.1
		Mean	24.7 ± 4.25[2]
Mung bean	Irregular (oval/round/bean-shaped)	Range	9.5–47.5.
		Mean	21.7 ± 3.68

1. Means and ranges of 100 measurements.

2. Standard error

Table 4. Gelatinization temperature, gel strength, gel consistency and degree of syneresis of pigeonpea and mung bean starches[1]

Crop	Gel Temp.[2] (°C)	Gel strength (Force, kg)	Gel consistency[3] (length, cm)	Degree of syneresis[4] (ml H_2O)
Pigeonpea				
Whole seed		1.4	3.0	2.9
Dhal	76	1.1	3.0	3.2
Mung bean				
Whole seed		2.5	3.3	1.1
Dhal	72	1.7	2.8	1.1
SE	±0.34	±0.04	±0.06	±0.02

1. All results are means of two determinations

2. gelatinization temperature at which 90% starch granules were stained.

3. Determined after heating 6% starch solution at 96°C for 8 min and after standing at room temperatures for 30 min.

4. Determined as the volume of water (ml) separated from 35 ml of 6% starch gel after storage at 4°C for 12 hr.

Table 5. Swelling power and solubility of dhal starches of [redacted] and mung bean at indicated temperatures[1]

Crop	Swelling power ($g\ g^{-1}$)				Solubility (%)			
	Temperature °C				Temperature °C			
	60	70	80	90	60	70	80	90
Pigeonpea	1.0	3.0	10.1	11.5	0.7	6.9	18.0	23.1
Mung bean	4.0	6.1	9.2	11.9	0.8	11.3	17.9	23.8
SE	±0.29	±0.81	±0.23	±0.21	±0.04	±1.22	±0.76	±0.19

1. Means of two determinations.

Table 6. Viscoamylographic properties of dhal starches of pigeonpea and mung bean[1]

Crop	Viscosity (Brabender units)				Set back[3]
	95°C		50°C	35°C	
	Initial	Final[2]			
Pigeonpea (cv C 11)	277	302	480	593	178
Mung bean (cv PS 16)	300	315	665	972	350
SE	± 6.5	± 5.8	± 12.4	± 15.8	± 7.9

1. Values obtained using 6% starch and average of two determinations.
2. After holding for 60 min.
3. Difference of readings at 50°C and after holding for 60 min at 95°C

Table 7. Sensory scores of soft and (hard) noodles prepared pigeonpea (cv C 11) and mung bean (cv PS 16) starch[1].

Crop	Color	Texture	Clarity	Uniform appearance	General acceptability
Pigeonpea					
Whole seed	1.6	2.0	1.7	2.3	1.9
Dhal[2]	3.6 (3.7)	2.6 (3.1)	3.5 (3.0)	3.4 (3.2)	3.4 (3.1)
Mung bean					
Whole seed	2.5	3.2	2.5	2.8	2.8
Dhal	2.8 (3.3)	2.9 (3.2)	2.6 (3.2)	2.3 (2.8)	2.6 (3.0)
SE	±0.34	±0.27	±0.30	±0.26	±0.30

1. Average values of ten panel members. Rating scale : 4 = excellent, 3 = good, 2 = fair, and 1 = poor.

2. Values within parentheses are for hard noodles.

Table 8. Organoleptic properties of pigeonpea and soybean tempeh[1]

Tempeh	Color	Texture	Flavor	Taste	General acceptability
Pigeonpea (Nylon)	2.5	2.8	2.2	2.5	2.5
Soybean	3.0	3.2	2.6	2.7	2.8

1. Score : 4 = Excellent, 3 = Good, 2 = Fair, and 1 = poor. Results are averages of five sensory panel members.

Table 9. Correlation matrix of various cooking quality parameters of white pigeonpea accessions[1].

Constituent	1	2	3	4	5
1. 100 seed mass	-	-			
2. Seed coat (%)	-0.40**				
3. Cooking time (raw)	0.02	0.24	-		
4. Cooking time (soaked)[2]	-0.09	0.01	0.57**		
5. Water absorption	0.11	-0.16	0.09	0.24	-

1. Based on analyses of whole seed of 57 accessions

2. Soaked for 16 hr in distilled water at room temperature (25°C ± 1°C)

Table 10. Cooking time and organoleptic properties of dhal samples some pigeonpea genotypes developed by ICRISAT, grown at ICRISAT Center, Patancheru, rainy season 1986.

	Protein[1] (%)	Cooking time (min)[1]	Water absorption ($g\ g^{-1}$)[1]	Solid dispersion (%)[1]	Color[2]	Texture[2]	Flavor[2]	Taste[2]	General acceptability
ICPL 87	20.8	22.0	1.30	50.4	3.0	3.5	3.2	2.8	3.2
ICPL 151	18.2	24.0	1.40	37.3	2.1	3.0	2.7	3.2	3.0
UPAS 120	20.8	23.0	1.40	30.3	3.0	3.0	3.0	3.0	3.0
Prabhat (ICPL 87)	20.8	23.0	1.40	43.3	2.2	3.5	2.5	1.8	2.0
ICPL 8863	22.1	22.0	1.40	44.1	2.7	3.3	3.2	2.8	3.2
UPL 40	27.8	29.0	1.10	27.4	2.7	2.8	2.7	2.7	2.7
UPL 8	25.7	28.0	1.20	45.5	2.8	3.2	2.8	3.0	3.0
ICPL 270	21.1	22.0	1.40	44.4	1.8	3.7	3.0	2.7	2.7
ICPL 8357	18.7	21.0	1.30	50.4	2.8	4.0	2.8	2.2	2.2
ICPL 211	20.8	23.0	1.10	20.3	2.5	2.5	2.5	2.2	2.2
ICPL 84060	23.6	24.0	1.10	30.2	3.5	2.5	2.3	2.0	2.7
BDN 1	25.2	24.0	1.30	31.8	3.0	2.7	3.0	3.3	3.1
C 11	22.6	24.0	1.20	46.2	2.8	3.3	2.7	3.0	3.1
ICPL 366	18.2	24.0	1.30	30.8	2.7	2.4	2.8	3.0	2.8
Gwalior 3	23.8	24.0	1.30	45.1	3.5	3.2	2.8	3.0	2.8
ICPL 8388	20.8	25.0	1.30	32.9	3.3	2.7	3.0	3.7	3.2
SE	±0.21	±1.25	±0.02	±0.45	±0.23	±0.28	±0.23	±0.31	±0.24

1. Based on two determinations

2. Based on sensory evaluation by six panel members

Table 11. Cooking quality characteristics of some ICRISAT genotypes grown and supplied by CARDI, Belize in 1986[1]

Genotype	Seed color	100 seed mass (g)	Seed coat (%)	Dhal yield[2] (%)	Protein (%)	Whole seed		Dhal
						Cooking time (min)	Water absorption ($g\ g^{-1}$)	Cooking time (min)
ICP 11528	White	14.3	10.50	81.9	18.7	57	1.5	43
ICP 11578	Cream	15.4	11.52	80.4	16.8	58	1.3	39
ICPL 146	Brown	9.3	13.86	78.8	17.2	55	1.3	39
ICP 11515	Dark cream	13.8	11.15	80.6	17.1	55	1.5	37
ICP 7035	Purple with dots	19.6	9.65	84.1	17.9	64	1.1	34
ICP 8324	Purple	16.7	10.24	80.8	15.7	64	1.4	27
ICPL 850012	Cream	11.3	12.5	80.2	16.4	58	1.4	28
ICP 11653	Purple+cream	15.7	11.11	78.8	17.3	60	1.4	25
ICP 7213	Cream	16.3	10.85	82.5	17.6	60	1.3	24
ICP 8533	Cream	15.2	11.97	81.4	17.1	76	1.3	26
ICP 11181	Brown	14.5	11.91	79.5	15.9	64	1.3	4
77807 TC P4 DT-B-BB-(I)B-B	White+brown	10.0	12.45	83.2	18.9	61	1.3	26
ICP 6920	White	15.0	10.83	80.6	17.3	52	1.8	21
ICP 11559	Cream	13.5	11.58	81.5	16.9	66	1.6	29
ICP 87-(B)	Brown	18.4	13.89	80.2	18.3	57	1.3	22
ICP 11145	Light brown	16.7	11.26	81.3	16.1	75	1.4	25
ICPL 269	Cream	11.0	12.33	80.8	18.9	58	1.3	26
ICPL 6909	Cream	16.9	10.98	82.2	16.6	56	1.7	28
Mean		14.3	11.55	81.0	17.2	60.8	1.4	29

1. Results are averages of two determinations excepting 100-seed mass for which five determinations were made. These genotypes were grown at CARDI, Belize during 1987/87.

2. Dhal yield obtained by using Tangential Abrasive Dehulling Device (TADD)

Table 12. Effect of location on protein and cooking time of whole seed of high (HPL), medium (MPL) and low protein lines (LPL) of pigeonpea (C 11) grown during 1986/87 season[1]

Genotype	Patancheru		Gwalior		S.K. Nagar		Jalana	
	Protein (%)	Cooking time (min)	Protein (%)	Cooking time (min)	Protein (%)	Cooking time (min)	Protein (%)	Cooking time (min)
HPL 25	25.7	53	26.8	50	25.2	52	27.6	50
HPL 35	25.2	47	26.6	50	23.9	49	28.2	56
MPL 1	23.7	57	20.9	60	21.8	62	23.4	63
MPL 9	23.9	54	19.4	53	22.9	52	24.0	59
LPL 1	21.9	56	20.3	56	18.9	50	21.6	60
LPL 12	18.6	48	19.2	44	17.3	47	19.1	46
C 11	20.9	55	19.8	51	19.4	54	21.6	54
BDN 1	21.0	54	19.9	54	19.5	50	21.0	52
SE[1]	±0.21	±0.54	±0.19	±0.32	±0.30	±1.12	±0.27	±1.32

1. Based on two determinations for each genotype.

Table 13. Chemical composition of dhal samples of high and normal protein genotypes[1]

Genotype	100-seed mass (g)	Protein (%)	Starch (%)	Soluble sugars (%)	Fat (%)	Ash (%)	Crude fib (%)
HPL 8	10.7	28.7	54.3	4.3	2.6	4.8	1.4
HPL 40	9.3	31.1	55.6	5.1	2.5	5.1	1.1
C 11	11.0	24.8	58.7	4.8	2.9	4.9	1.2
ICPL 211	12.7	23.1	59.3	4.2	3.1	5.0	1.4
SE	±0.34	±0.09	±0.30	±0.06	±0.02	±0.03	±0.03

1. Averages of two determinations and expressed on dry weight basis.

Table 14. Protein fractions of dhal sample of high and normal protein genotypes[1]

Genotype	Protein (%)	Albumin	Globulin	Glutelin	Prolamin	Total
		[g(100 g)$^{-1}$ protein]				
HPL 8	28.7	9.1	63.5	20.2	2.9	95.7
HPL 40	31.1	8.0	66.2	19.7	3.2	97.1
C 11	24.8	7.7	60.5	23.3	3.6	95.1
ICPL 211	23.1	8.6	60.3	22.8	2.1	94.5
SE	±0.09	±0.34	±1.08	±0.75	±0.06	-

1. Averages of two determinations and expressed on dry weight basis

Table 15. Amino acid composition [g(100 g)$^{-1}$ protein] of high and normal protein genotypes

Amino acid	HPL 8	HPL 40	C 11	ICPL 211	SE
Lysine	5.5	5.8	5.8	6.0	± 0.07
Histidine	3.2	3.2	3.2	3.3	± 0.03
Arginine	5.7	6.3	5.8	5.6	± 0.02
Aspartic acid	8.7	8.7	8.7	8.9	± 0.14
Threonine	2.0	2.9	3.0	3.0	± 0.11
Serine	4.1	4.0	4.1	4.3	± 0.07
Glutamic acid	20.5	20.0	21.2	21.3	± 0.21
Proline	3.7	4.1	4.4	4.8	± 0.12
Glycine	3.4	3.2	3.4	3.3	± 0.05
Alanine	3.6	3.7	3.9	4.0	± 0.03
Cystine	0.8	0.8	0.7	0.7	± 0.01
Valine	3.6	3.7	3.9	4.1	± 0.06
Methionine	1.0	1.0	1.1	1.1	± 0.02
Isoleucine	3.4	3.2	3.5	3.6	± 0.05
Leucine	6.4	6.4	6.7	7.0	± 0.08
Tyrosine	2.6	2.5	2.7	2.7	± 0.03
Phenylalanine	8.3	7.9	8.1	8.7	± 0.09
Protein (%)[1]	29.9	32.5	25.7	24.2	± 0.09

1. Analysis of defatted dhal samples (N x 6.25, dry weight basis)

Table 16. Trypsin inhibitor activity (TIA) and chymotrypsin inhibitor activity (CIA) of raw and cooked dhal sample of high and normal genotypes

Genotype	TIA				CIA		
	Raw		Cooked[3]		Raw		Cooked[3]
	1	2	1	2	1	2	
HPL 8	7.2	25.1	0.4	1.5	3.5	12.2	ND
HPL 40	5.4	17.4	0.7	2.3	3.8	12.4	ND
C 11	4.8	19.4	0.4	1.7	2.2	8.9	ND
ICPL 211	6.9	24.8	0.3	1.3	2.4	10.4	ND
SE	±0.34	±0.75	±0.08	±0.18	±0.06	±0.26	-

1. Enzyme units inhibited/mg meal.

2. Enzyme units inhibited/mg protein

3 Cooked for 15 min at 1.05 kg cm^{-2}

ND = Not detected.

Table 17. Biological evaluation of raw and cooked whole seed samples of high and normal protein genotypes[1]

Genotype	Raw					Cooked[2]				
	Protein[3]	TD	BV	NPU	UP	Protein[3]	TD	BV	NPU	UP
	(%)									
HPL 8	25.6	58.5	68.7	40.2	10.3	24.4	79.4	68.5	54.4	13 3
HPL 40	27.3	58.0	70.5	40.9	11.2	27.6	75.8	66.4	50.3	13.9
C 11	21.9	59.5	64.3	38.3	8.4	22.2	75.6	62.5	47.3	10.5
ICPL 211	21.0	60.6	64.0	38.8	8.1	20.9	74.9	64.5	48.3	10.1
SE	±0.48	±1.08	±1.13	±0.64	±0.23	±0.32	±1.35	±1.07	±1.01	±0 31

1. TD = True protein digestibility, BV = biological value, NPU = net protein utilization (TD x BV/100), UP = utilizable protein (Protein x NPU/100), based on five determination for each treatment

2. Cooked for 15 min at 1.05 kg cm^{-2}

3. Protein = N x 6.25 (dry weight basis).

Table 18. Biological evaluation of cooked and raw sample of dhal of high and normal protein genotypes[1]

Genotype	Raw					Cooked[2]				
	Protein[3]	TD	BV	NPU	UP	Protein[3]	TD	BV	NPU	UP
	(%)									
HPL 8	28.7	71.5	75.8	54.2	15.6	27.6	83.7	67.0	56.1	15.5
HPL 40	31.1	69.8	73.6	51.4	16.0	30.8	82.9	65.3	54.1	16.7
C 11	24.8	72.3	73.6	53.2	13.2	23.9	84.3	66.7	56.2	13.5
ICPL 211	23.1	70.8	76.4	54.1	12.5	22.8	85.7	62.9	53.9	12.3
SE	±0.28	±0.98	±1.14	±1.23	±0.34	±0.26	±2.14	±1.68	±1.06	±0.25

1. TD = True protein digestibility, BV = biological value, NPU = net protein utilization (TD x BV/100), UP = utilizable protein (Protein x NPU/100), based on five determinations for each treatment
2. Cooked for 15 min at 1.05 kg cm^{-2}
3. Protein = N x 6.25 (dry weight basis).

Table 19. Effect of cooking time on biological value, true protein digestibility and net-protein utilization in pigeonpea C 11, ICRISAT Center, 1986/87[1]

Treatment		Food consumed (g)	Biological value (%)	True protein digestibility (%)	Net protein utilization (%)
Whole seed					
	Raw	44.2	70.5	61.1	43.1
	Cooked	41.0	64.7	77.8	50.3
	SE	±3.32	±2.05	±1.13	±1.80
Dhal					
	Raw	41.9	77.7	71.0	55.2
	Cooked	44.7	69.6	83.0	57.8
	SE	±1.87	±1.37	±1.60	±1.63

1. Based on five determinations for each treatment.

Table 20. Amino acid composition [g(100 g)$^{-1}$] of raw and cooked samples of C11 and Nylon

	C 11				Nylon			
	Raw		Cooked		Raw		Cooked	
Amino acid	1	2	1	2	1	2	1	2
Lysine	6.65	6.71	6.20	6.15	6.84	6.88	6.33	6.40
Histidine	4.06	4.08	3.79	3.77	4.16	4.03	4.03	3.96
Arginine	6.53	6.59	6.29	6.35	6.44	6.99	6.71	6.83
Aspartic acid	9.16	9.19	9.26	9.32	9.57	9.56	9.60	9.42
Threonine	3.54	3.50	3.65	3.49	3.62	3.78	3.67	3.42
Serine	4.45	4.46	4.25	4.09	4.57	4.32	4.73	4.39
Glutamic acid	17.55	17.97	17.19	17.42	17.86	17.76	18.37	18.40
Proline	4.43	4.54	4.48	4.59	4.52	4.59	4.74	4.66
Glycine	3.56	3.71	3.54	3.77	3.69	3.66	3.87	3.64
Alanine	4.20	4.29	4.25	4.79	4.27	4.50	4.36	4.37
Cystine	0.79	0.90	0.66	1.54	1.45	1.39	1.44	1.46
Valine	4.25	4.35	4.44	4.34	4.61	4.74	4.82	4.63
Methionine	1.49	1.43	1.60	1.54	1.45	1.39	1.44	1.46
Isoleucine	3.84	3.86	3.88	3.85	4.01	4.20	4.25	3.96
Leucine	6.89	6.97	6.94	6.94	7.14	7.22	7.43	7.32
Tyrosine	3.07	3.07	33.07	3.08	3.18	3.58	3.48	3.71
Phenyalanine	8.50	8.66	8.48	8.58	9.00	9.39	9.56	9.66
Total	92.96	94.28	91.82	92.97	96.00	99.65	98.73	96.99
Protein (%)[3]	21.05	22.32	21.48	23.09	21.05	22.32	20.63	21.75

1. Whole seed; 2. dhal; 3. Defatted N x 6.25

Table 21. Biological evaluation of pigeonpea genotypes different in seed coat color, C 11 (brown seed) and Nylon (white seed coat), ICRISAT Center, 1986/87.

Genotype	Food consumed (g/rat)		True protein digestibility (%)		Biological value (%)		Net protein utilization (%)	
	1	2	1	2	1	2	1	2
Raw								
C 11	41.5	42.0	59.2	71.3	68.5	76.6	40.6	54.6
Nylon	45.0	44.7	68.0	73.5	73.6	77.8	50.0	57.2
SE	±1.80	±2.13	±1.45	±2.24	±1.85	±1.76	±2.03	±0.93
Cooked								
C 11	43.7	45.3	75.9	87.4	62.7	69.4	47.6	60.7
Nylon	46.5	44.0	84.6	88.5	69.4	70.6	58.7	61.6
SE	±0.64	±0.53	±1.34	±1.67	±0.98	±1.32	±0.87	±1.30

1. Whole seed; 2. Dhal, based on five determinations for each treatment

Table 22. Polyphenols (mg g^{-1} sample) of whole seed and dhal samples of C 11 and Nylon[1]

Cultivar	Seed coat (%)	Raw		Cooked	
		Whole seed	Dhal	Whole seed	Dhal
C 11	15.2	13.5	1.4	14.0	1.2
Nylon	12.7	4.8	1.1	4.5	1.0
SE	±0.30	±0.26	±0.06	±0.29	±0.04

1. Based on two determinations for each treatment.

Table 23. Effect of storage time on cooking quality of vegetable pigeonpea (cv Nylon) stored at two different temperatures, ICRISAT Center, 1986/87[2]

Storage time days	Room temperature (25°C)				Cold room temperature (5°C)			
	Moisture (%)	Cooking time (min)	Texture (hardness)[2]		Moisture (%)	Cooking time (min)	Texture (hardness)[2]	
			Raw	Boiled (10 min)			Raw	Boiled (10 min)
0	63.7	13	9.88	3.75	63.7	-	-	-
1	61.6	15	12.28	4.66	61.6	13	10.85	4.06
2	61.0	15	12.85	4.66	61.1	13	11.65	4.19
3	59.7	16	16.05	5.05	60.9	13	12.52	4.43
4	59.6	18	-	7.36	60.7	15	13.68	4.71
SE	±0.56	±0.24	±0.84	±0.43	±1.06	±0.3	±0.34	±0.18

1. Pods were harvested at the vegetable stage and stored at two different temperatures, results are averages of two determinations
2. Peak area (cm^2) measured using an extrusion cell in Instron Food Tester

Table 24. Effect of pretreatments on dehulling quality[1]

Treatment	Dhal yield (%)	
	Method 1	Method 2
1. Sodium chloride (1%)	81.3	81.1
2. Sodium carbondate (1%)	81.2	81.0
3. Sodium bicarbonate (1%)	80.4	80.3
4. Oil (0.25% w/w)	80.6	80.3
5. Water	80.8	80.6
6. Control	81.0	81.7
SE	±1.34	±2.01

1. After treatment, samples were dehulled using in a Tangential Abrasive Dehulling Device (TADD) mill.

$$\text{Method 1} = \frac{W_1}{W_2} \times 100$$

$$\text{Method 2} = \frac{W_1 - \text{seed coat}}{W_2} \times 100$$

Whereas W_1 = Weight of dehulled grain

W_2 = Weight of whole seed used for dehulling

Seed coat in dehulled grain was determined by manually removing the seed coat after dehulling in TADD mill.