INCAP Publication I-1315

En: Chemistry and World Food Supplies: The New Frontiers - CHEMRAWN. (Papaers presented at the International Conference on Chemistry and World Food Supplies, Manila, Philippines, 6 - 10 December, 1982). L. W. Shemilt (Ed.). New York, Pergamon Press, 1983.

EFFECTS ON NUTRITIONAL QUALITY OF FOOD LEGUMES FROM CHEMICAL CHANGES THROUGH PROCESSING AND STORAGE

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ABSTRACT

To demonstrate the effect on nutritive value arising from chemical changes induced by storage and processing of food, legumes were chosen because of their importance in human diets. Chemical components, most of them nutrients, found in foods as produced are affected by production, storage, processing and consumption conditions. The understanding of the chemical changes taking place is essential to maximize nutrient utilization. Improper storage will increase the hard-to-cook condition in common beans already initiated during post-harvest processing. Dry or wet processing techniques, if properly carried out, will inactivate anti-physiological substances and increase nutritive value. Improper processing will result in low digestibility of the protein. Germination and fermentation result in higher levels of vitamins and increased availability of nutrients, but germination effects have given contradictory results. Inadequate storage of processed food legumes reduce their nutritional value and thus the nutritional quality of diets. Recommendations for research include the understanding of the hard-to-cook problem, the chemical nature of low protein digestibility, and resistance to insect attack.

KEYWORDS: processing; storage; food legumes; nutritive value.

INTRODUCTION

Storage and processing of foods are technologies which man has always used as a pre-requisite for insuring availability of the food supply, and in many cases as a necessary step before consumption for such reasons as increasing stability, improving flavor, decreasing the possibilities of intoxication, and introducing functionality. All these end points of storage and processing of food influence to variable degrees the nutritional value of the food.

Chemistry plays an important role in the food chain from production to consumption, and the nutrients or chemical compounds synthesized by the plant and deposited in the seed interact with each other during storage and processing to give specific nutritional values. This suggests the need for geneticists and production specialists to work closely with food chemists and technologists as well as with biochemists and nutritionists to insure the maximum nutritive quality and acceptability to the consumer.

This paper selects common beans as the commodity whose nutritional value is affected by a variety of factors during storage and processing. Areas of research needed as a means to increase the availability, use and nutritive value of a food of great nutritional significance to people in developing countries are also pointed out.

POST-HARVEST PROCESSING

Processing For Storage

After harvest, common beans usually contain relatively high amounts of moisture which have to be removed before storage. It is a common practice by small farmers in developing countries to expose the grain to solar radiation. The exposure time is more or less well controlled, otherwise the beans will become hard. This has been confirmed by experimental studies (Table 1). As solar exposure time increased, there was an expected decrease in moisture content, and a decrease in water absorption and cooking time. Changes in other chemical constituents also took place, the significance of which is not well understood. However they probably have significant implications in the hard-to-cook condition often developing in common beans and other food legumes subjected to storage (Sefa-Dedeh et al., 1979; Burr and Kon, 1966, Molina et al., 1976)

Table 1: Physical and Chemical Characteristics of Recently Harvested Common Beans Exposed to Solar Radiation Prior to Storage (Garcia and Bressani, 1982)

Solar radiation cal	Moisture %	Water Absorption %	Cooking quality[1] %	Soils in cooking broth g	Soluble pectins %
0	15.2	33.4	20.0	3.98	5.77
91	13.7	30.4	18.0	3.60	5.46
390	12.0	20.4	8.0	2.00	4.69
1416	10.7	7.4	4.0	1.78	4.43

[1] Broken grains

The Hard-to-cook Phenomenon

Storage of common beans under improper conditions increases the hard-to-cook problem. In the example shown in Figure 1, common beans were stored for 0, 3 and 6 months at $35\,^{o}C$ and 85% relative humidity (Bressani, 1982). At the end of storage, samples were cooked under standard procedures at atmospheric pressure and their hardness measured by the Instrom texturometer. A standard cooking hardness as g-force of 90 was chosen on the basis of current home practices in Guatemala. As seen in Figure 1, it required 150 min. and 170 min. at atmospheric pressure to cook soft the samples stored for 0 months and 3 months respectively, but those stored for 6 months were still uncooked at 210 min. This hard-to-cook condition has significant economic implications both through lack of acceptability and energy cost increases. Furthermore, excessive cooking, which is often applied to soften the grain, will decrease protein quality as shown in Figure 1 for Phaseolus vulgaris. The loss in protein quality is the result of a lower protein availability as well as a loss in lysine, which becomes inactivated through the well known Maillard reaction effect shown by various investigators (Bressani et al., 1963; Almas and Bender, 1980). An interaction between storage and processing can also affect the nutritional value of legume foods. In some instances a high cooking time is needed to obtain a maximum possible nutritive value from the hard-to-cook beans. Table 2 shows that even after 240 min. cooking time digestibility of hard-to-cook beans was significantly lower compared to recently harvested beans. The factors involved are temperature, time, relative humidity, and the moisture content of the seed (Burr and Kon, 1966). The mechanism of the hard-to-cook condition is not known.* The evidence available suggests an increase in the bound protein probably taking place in the seed coat and aleurone layer. However, the cotyledons also lose the capacity to absorb water due to changes in pectins and calcium ions, and very often they develop a gray color, suggestive of carbohydrate protein reactions (Varriano-Marston and Omana, 1979; Sefa-Dedeh et al., 1978).

LIMITING NUTRITIONAL FACTORS OF COMMON BEANS

A. PHYSICAL FACTORS: HARD-TO-COOK

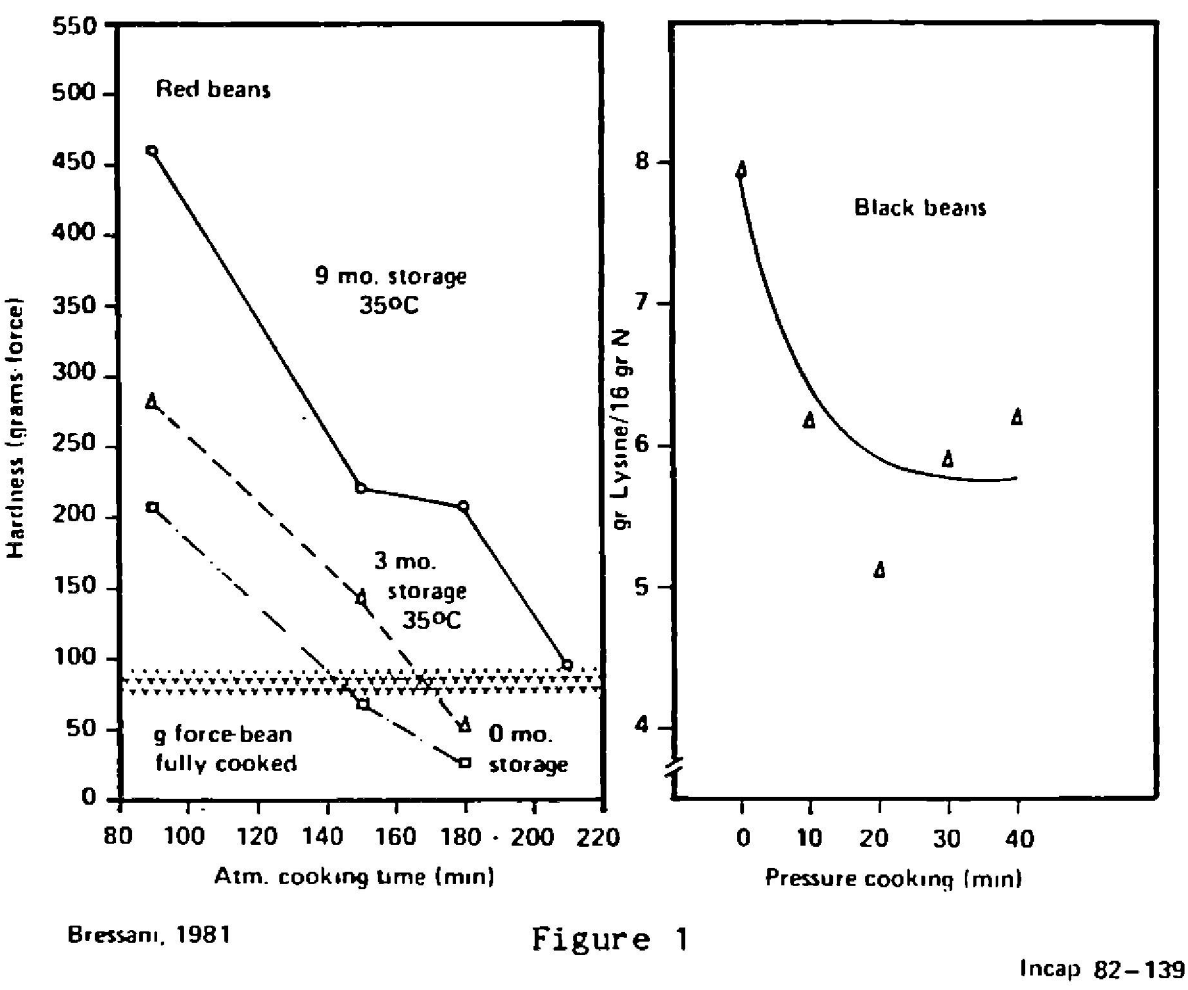

Figure 1

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* Editor's Footnote

During discussion following presentation of this paper, it was noted by Prof. D. Boulter that recent work had clarified the mechanism leading to hard-to-cook beans (c.f. Jones, P.M.B. and D. Boulter, Hardbean Symptoms: Their Cause and Relevance to Textural Deteriorations, J. Food Sci. (in press); Jones, P.M.B. and D. Boulter, The Analysis of Development of Hardbean During Storage of Black Beans (Phaseolus vulgaris L), Qualitas Plantarium: Plant Foods for Human Nutrition (in press)).

Table 2: Effect of Storage and Processing on the Digestibility Values of Hard-to-cook Beans

Cooking time min.	Apparent Digestibility
60	48.2
120	55.7
180	58.3
240	57.3
60	69.3
Recently harvested beans	

Table 3: Protein Quality of Chickpea and Pigeon Pea Infested by Insects

Food Legume	PER	% decrease
Chickpea dhal (control)	2.21	-
Chickpea dhal (infested)	1.83	17.2
Pigeon pea (control)	2.04	-
Pigeon pea (infested)	1.66	18.6

Insect Infestation

Studies carried out in India (Parpia, 1972) shown in Table 3 indicate that chickpeas or pigeon peas lost about 18% of their protein quality due to insect infestation. The loss may be due to contamination from uric acid, as well as from increases in fat acidity and microbial contamination, and even losses of grain fractions. Resistance to insect attack has been reported for common and Faba beans (Pabon et al, 1976; Tahhan and Hariri, 1981). Thus, natural resistance to insect infestation may exist. Identification of the nature of this resistance would help alleviate storage problems reduce chemical treatment for insect control, maintain nutritive value and insure increased efficiency of processing.

PROCESSING

Milling

Although not universally used, in certain regions of the world food legumes are milled to remove the seed coat before the application of thermal processing. Storage conditions have significant quantitative and qualitative effects on legume milling. Both wet and dry milling may be carried out at the household or commercial level (Siegel and Fawcet, 1976). The wet method usually takes longer, and although yields are good, the cotyledons (dhal) become hard-to-cook, requiring longer cooking times. The dry method of dehulling has the disadvantage of producing high milling losses due to breakage of cotyledons and powdering. Furthermore, the loosening of the seed coat in this process is not adequate, much less when the drying operation of beans before storage has not been adequate. In addition, if the grain is insect infested, milling yields decrease (Parpia, 1972). Milling techniques have been developed to maximize the yield of the edible fractions and data have been obtained suggesting that the genetic make up of the cultivars also play an important role in the yield of edible fractions.

Roasting

Roasting is an interesting processing technique since it has a special attribute of developing attractive flavors in the food. It also induces important functional properties which should be compatible with nutritional value. An example of roasting for cooking Vicia faba is shown in Table 4. This product, converted into a fine flour, is utilized as a drink for young children in some developing countries (Bressani et al., 1981). About 15 minutes of roasting at 200°C was the optimum time for maximum protein quality. Chemical analysis for available lysine showed an expected decrease in this amino acid, which explains the lower quality as roasting time increased. The roasting process has been applied to processing of common beans (Table 5, Yadav and Liener, 1978) using a bed heat exchange dryer operated at 190-200°C for 20 to 30 second.

Table 4: Effect of Roasting Time on the Protein Quality of Vicia Faba

Roasting time min. @ 200°C	PER
0	0.86
7.5	1.00
15.0	1.12
22.5	1.06
25.0	0.75

Table 5: The Protein Quality of Autoclaved and Dry Roasted Navy Beans

Process	Trypsin inhibitor	Hemagglutination units/g x 10^{-3}	P.D. %	PER
Autoclaving, min				
0	16.5	35.5	44.3	-
15	2.5	0.2	66.0	1.69
30	0	0	66.4	1.46
60	0	0	62.8	1.15
Dry roasted 20-25 sec 196-200°C	4.1	0.2	69.2	1.92

Based on the parameters measured, roasting resulted in a product as good or higher in protein quality as that processed by the common wet cooking procedure under pressure. Thus well controlled processing conditions remove the danger of reducing the food's nutritional potential.

Heat treatment is also very useful in preserving the cooking characteristics of whole food legumes which become hard-to-cook upon storage, as indicated above. In one study, whole black beans were heat-treated for 2, 5 and 10 minutes at 121°C and for 10, 20 and 30 minutes under steam (98°C). The materials so treated were then stored at 25°C and 70% relative humidity and samples were withdrawn at 3, 6 and 9 months for cooking quality evaluation (Molina et al., 1975; Molina et al., 1976). The results indicated that the process ensured that the beans retained acceptable cooking characteristics as compared to the untreated control, which was more hard-to-cook as time of storage increased.

Cooking

Wet cooking is probably the most common procedure used to prepare food for consumption, both at home and industrially. Common beans must be cooked for consumption for the purpose of inactivating the presence of antiphysiological factors (Liener, 1969; Tobin and Carpenter, 1978). This is shown in Figure 2 where the effect of processing on inactivating trypsin inhibitors and hemagglutinins is given on the left, while the improvement in protein quality is given on the right. The antiphysiological factors are destroyed in about 90 minutes, which results in an increase in protein quality. However, exceeding cooking time results in a progresive loss in nutritive value due to losses of lysine. The wet cooking process may be carried out under pressure which reduces the time of exposure as compared to cooking at atmospheric pressure.

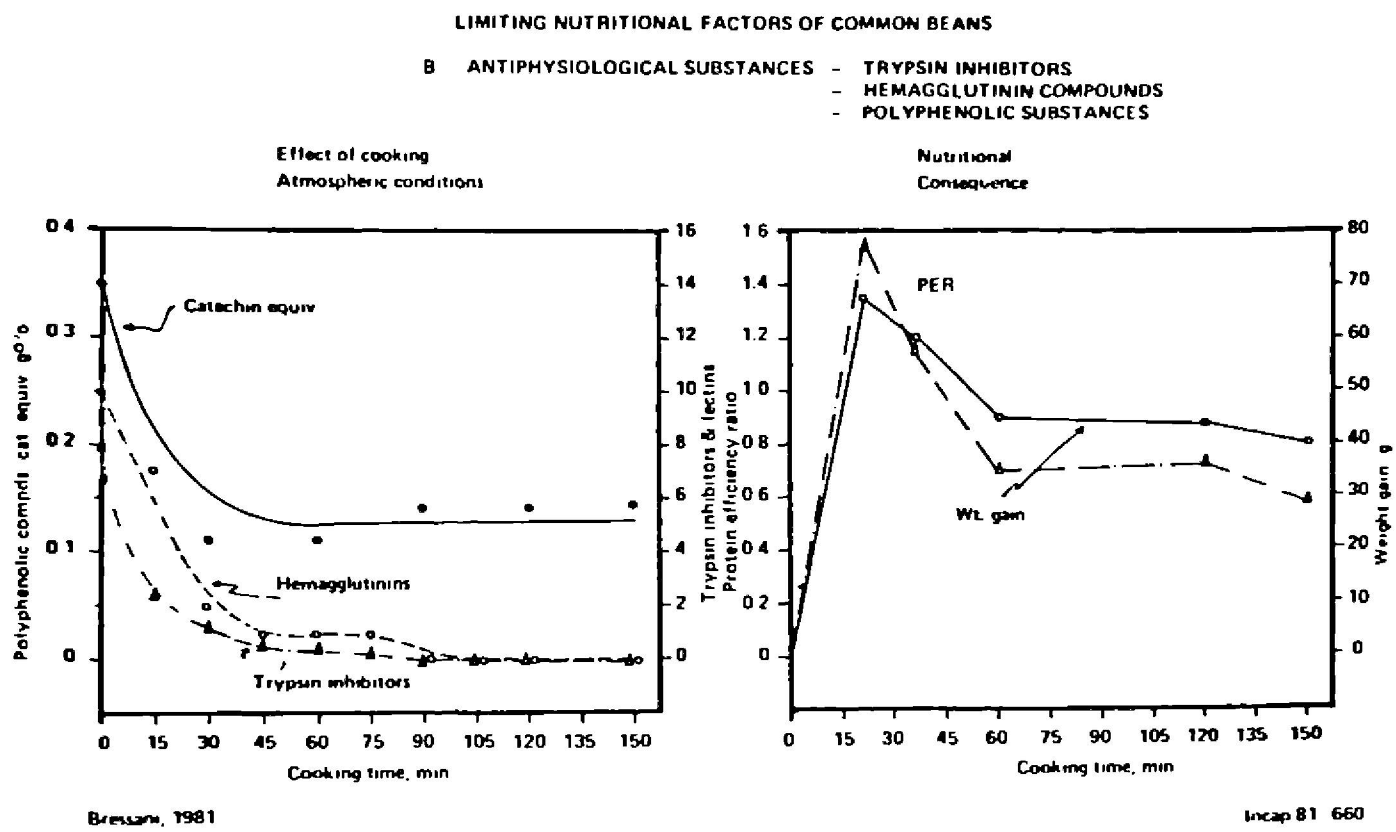


Figure 2

Drum Drying

Drum drying is another technique employed for cooking foods for consumption. Important processing conditions include temperature, residence time (both dependent on drum velocity), space between drums and solids concentration. It is an attractive technology since in one operation the material is cooked and dried. Results of samples of beans processed by this technique in comparison with autoclave and extrusion cooking are shown in Table 6. As shown drum drying was capable of giving a product higher in protein quality than autoclave cooking, particularly for cowpeas (Bressani et al, 1977).

Extrusion Cooking

One of the most recent processing techniques in food processing is extrusion cooking. This process may be carried out with some water addition. The data in Table 6 show an increase in protein quality taking place by extrusion cooking, over samples from autoclave cooking and drum drying. The possible reasons for the increase by extrusion cooking is that this procedure caused a greater inactivation of antiphysiological factors and increased the susceptibility of the protein to a

Table 6: Effect of Cooking of Food Legumes by Autoclaving, Drum-drying and Extrusion (Bressani et al., 1977)

Process		Cowpea/common beans 50/50	Cowpea
Autoclave	Wt. gain, g/28 days	41.00 ± 6.80	44.00 ± 4.20
	PER	2.33 ± 0.18	1.47 ± 0.09
Drum-drying	Wt. gain, g/28 days	28.00 ± 0.40	52.00 ± 2.60
	PER	1.38 ± 0.08	1.97 ± 0.52
Extrusion	Wt. gain, g/28 days	48.00 ± 4.90	75.00 ± 5.20
cooking	PER	1.54 ±0.04	2.12 ± 0.06

more complete hydrolysis, or that there is a change in the carbohydrate fraction which favors a better protein utilization (Bressani et al, 1977).

Germination

It is generally known that germination has a marked effect on improving the nutritional quality of legumes. A dramatic increase in ascorbic acid and of other vitamins in legume seeds has been observed during germination. However, many contradictory results are reported in the literature. Most indicate that trypsin inhibitors activity is retained in germinated food legumes without affecting nutritive value, an observation deserving more research. Likewise, starch is broken down, and flatulence factors as well as polyphenolic content are reduced (Chen et al., 1975; Fordham and Wills, 1975; Everson et al., 1944; Kakade and Evans, 1966; Noor et al., 1980; Chandrasekhar and Jayalakshmi, 1978; Chattopadhyay and Banerjee, 1953; Singh and Jambunathan, 1981; Khaleque et al., 1983).

A significant decrease in the nutritive value of common beans has been found (Elias et al, 1973) as shown in Table 7. Protein efficiency ratio decreases significantly with respect to germination time which in part can be due to a decrease in the total sulfur amino acid content, since apparent protein digestibility showed no major changes until the end of the germination period. Although not shown in this Table, the protein fraction extracted with 5% KCl increased during germination, while soluble proteins in water and in 70% ethanol remained unchanged. The latter should be the object of further investigation, since available amino acid composition will depend on the protein fraction that prevails at different stages of the germination period. The differences in results reported from food legume germination may be associated with food legume species, an aspect which should be studied.

Fermentation

The processing of food by fermentation, an ancient practice, is used quite extensively in various parts of the world, particularly in the Orient. Some general observations made include increases in B_{12} as well as in other vitamins of the B-complex group. Likewise, there are increases in protein quality, increased availability of various nutrients and removal of antiphysiological substances. Of particular significance is the supplementary effect induced by the microbial growth on the substrate (Dworschak, 1982). Although fermentation is usually carried out on the food legume itself, from the nutritional point of view, fermentation of mixtures of legumes and cereal grains have attractive perspectives. An example of this is shown in Table 8 (Wang et al., 1968).

Table 7: Changes in the Nutritive Value of Common Beans (Phaseolus vulgaris) During Germination

Days of germination	Total sulfur amino acids g/16 g N	Ave. wt. gain in 4 weeks, g	Protein efficiency ratio (PER)	Apparent digestib. %
0	1.44	28	0.99	67
3	1.25	24	0.86	64
6	1.21	15	0.59	67
9	1.15	4	0.26	60

Table 8: Weight Gain, Food Consumption and Protein Efficiency Ratio of Rats Fed Fermented or Unfermented Grains as Protein Sources

Protein sources	Weight gain, g	Food consumption, g	PER
Casein	98.0 ± 6.6[1]	347 ± 13[1]	2.81 ± 0.10[1]
Wheat (control)	37.6 ± 2.7	295 ± 13	1.28 ± 0.05
Wheat (fermented)	55.0 ± 1.6[2]	322 ± 7[2]	1.71 ± 0.05[2]
Soybeans (control)	76.5 ± 2.3	353 ± 10	2.17 ± 0.03
Soybeans (fermented)	72.9 ± 3.3	321 ± 12[2]	2.27 ± 0.05
Soybean/Wheat (control)	97.1 ± 3.2	389 ± 8	2.49 ± 0.04
Soybean/Wheat (fermented)	94.2 ± 2.2	338 ± 12[2]	2.79 ± 0.04[2]

1 Standard error
2 Significantly different (P $\leq$ 0.05) from corresponding unfermented grain.

Mixtures of soybean with wheat (in a 60/40 ratio on the basis of protein) give a food of a protein quality higher than that of the single components (Bressani, 1974). If these foods individually or combined are fermented through the use of a microorganism, such as Rhizopus oligosporus, there are important increases in protein quality (Table 8). The fermented product in every case showed a higher ptoein quality increase which depends on the protein quality of the food to be fermented. For example, wheat quality increased much more than soy quality, because the protein of the microorganisms contain lysine, deficient in wheat, but is deficient in methionine, which is also deficient in soybean protein.

STORAGE OF PROCESSED FOOD LEGUME PRODUCTS

Processed bean products include canned beans as well as powders. However, studies of the effect of storage on nutritive value are few. The powders if not properly stored may become damaged rather easily, and one example for soybean flour, is shown in Table 9. Samples, classified by color were taken for chemical and biological analysis. Available lysine was acceptable in the light colored samples, but it was significantly low in the dark colored samples. The loss in available lysine reflected itself in the loss of protein quality of the product (INCAP, unpublished data). Similar results have been reported to take place with other food products, particularly milk powder often shipped by developed to developing countries for purposes of distribution in supplementary feeding programs. Losses of foods through improper handling and storage conditions obviously have significant economic and nutritional implications which may be reduced or eliminated by improving storage conditions. Similar observations have been made with bean powders, made by moist cooking in the autoclave followed by deydration and stored in paper and polyethylene bags at ambient temperature. In biological trials, decreased protein quality of the product (Elias et al., 1973) resulted from prolonged storage and increases in free fatty acid content.

Table 9: Effect of Storage on the Nutritive Value of Soybean Meal (INCAP, unpublished data.)

Soybean meal color	Available lysine g/16 g N	Prot. Dig. %	NPR
Light yellow	5.82	86.6	3.89
Yellow/Brown	5.34	88.7	3.43
Light brown	4.45	83.5	2.58
Dark brown	1.78	26.1	0.80
Casein	-	-	4.53

OTHER PROCESSING PROBLEMS WITH COMMON BEANS

Recently, the results of various studies have indicated that common beans contain polyphenolic compounds which interfere with protein digestibility and protein quality (Bressani and Elias, 1979), as indicated in Figure 3 for human studies (Bressani et al., 1981).

The partition of polyphenolics during and after cooking has been studied (Bressani et al., 1981) as shown in Table 10. Of the total polyphenolics in raw beans, expressed as tannic acid, the amounts remaining after cooking are shown along with the amounts in the cooking liquor. If no destruction of tannins takes place, it can then be assumed that the balance became bound. Bound tannins would be those polyphenolic compounds not measured by present analytical methods, since they have reacted with amino groups of the protein and are thus not extracted by methanol, and would be responsible for the decrease in protein digestibility. To understand the effect of the polyphenolic compounds on digestibility, it is necessary to establish the fate and role of these compounds during cooking, an area which should receive increased attention, including improved analytical techniques for such compounds.

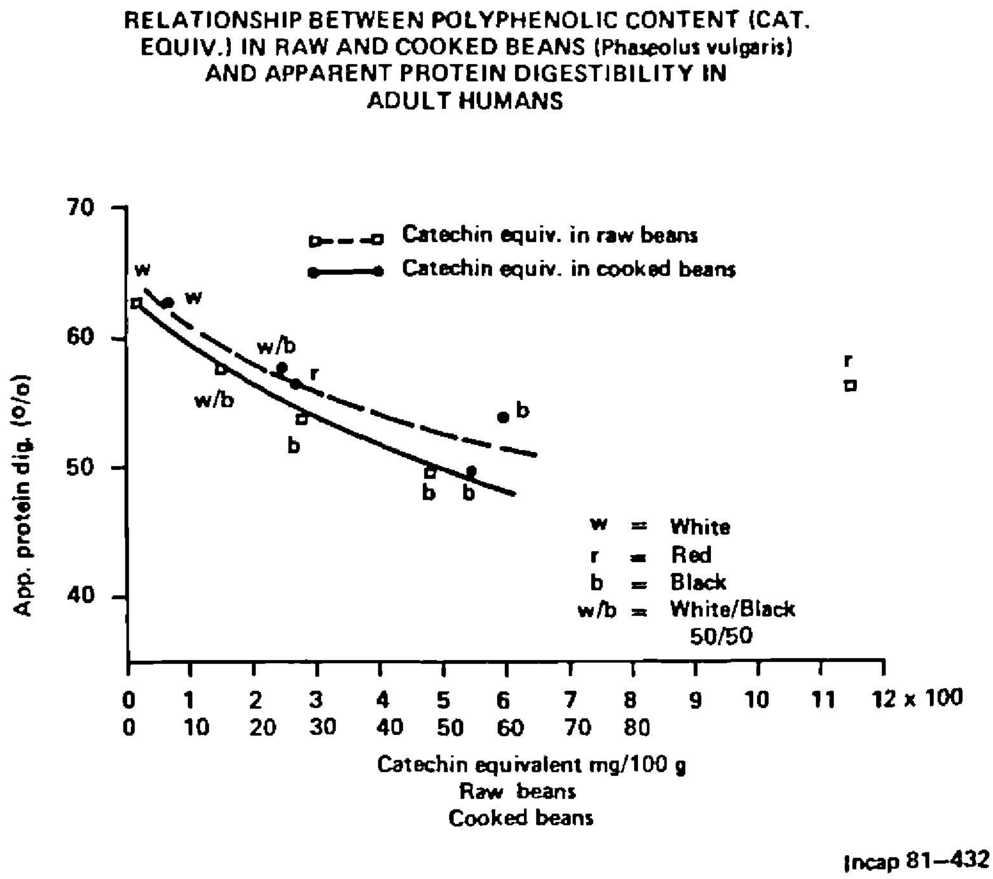


Figure 3

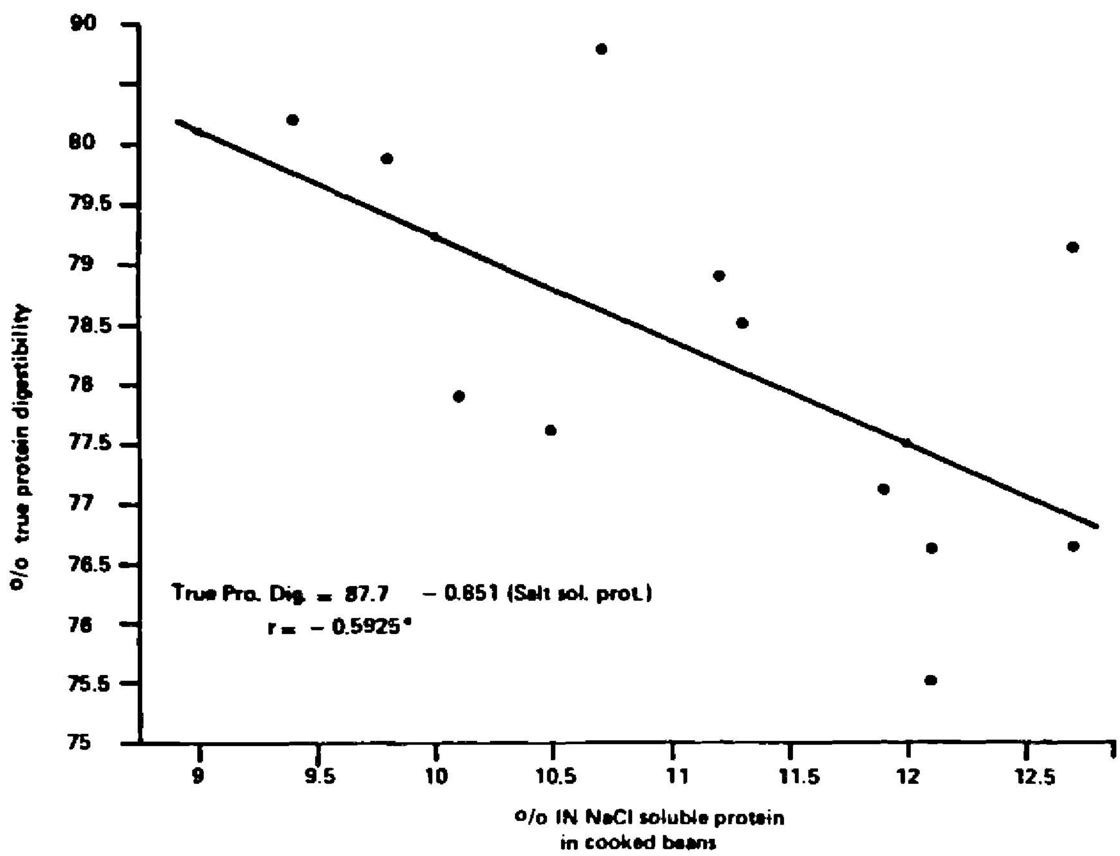
A second problem is related to the possible presence in beans of proteins resistant to enzymatic action even after "appropriate cooking". This fraction found in cooked beans decreases protein digestibility as shown by the regression equation in Figure 4. In this case the alkali soluble fraction in cooked beans, amounting to 9-20% of the total, negatively influenced protein digestibility in rats. Similar results have been obtained in dogs (Bressani et al, 1977) and, even more important, in human studies (Bressani et al, 1982) in which a negative correlation ($Y = 95.81 - 1.17 X$, $r = -0.94$) was also found. This is also another area which deserves additional research because the nutritional potential of bean protein is diminished by these two factors.

Table 10: Partition of Polyphenolic Compounds in Beans Upon Cooking

	Bean Color		
	Black	White g/500 g	Red
Raw bean	4.50	1.80	7.35
Cooked bean	2.72	1.20	2.75
Cooking liquor	0.86	0.28	0.86
		% Distribution	
Raw bean	100.0	100.0	100.0
Cooked bean	60.4	66.7	37.4
Cooking liquor	19.1	15.5	11.7
Bound (?)	20.5	17.8	50.9

Figure 4

RELATIONSHIP BETWEEN SALT SOLUBLE PROTEINS IN COOKED BEANS AND THEIR TRUE PROTEIN DIGESTIBILITY



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