Limitations of corn (*Zea mays*) and common bean (*Phaseolus vulgaris*) diets as protein and calorie sources*

G. CONTRERAS, L.G. ELIAS, and R. BRESSANI

Institute of Nutrition of Central America and Panama, Division of Agricultural and Food Sciences, Institute of Nutrition of Central America and Panama, P. O. Box 1188, Guatemala City, Guatemala

Abstract. Mixtures of 70:30 and 87:13 of corn and beans with or without vitamins, minerals, limiting amino acids and calories were fed to 5-week-old pigs to determine performance and efficiency of utilization. After 12 weeks it was shown that increasing the ratio from 87:13 to 70:30 (corn:beans) was a desirable measure as was the simultaneous supplementation with the other nutrients; individual groups of nutrients resulted in partial improvement in animal performance. None of the diets used was capable of inducing growth similar to the control groups fed a corn:soya diet. Results confirm the importance of total nutrients to obtain increased efficiency of protein utilization; furthermore, diets, such as the corn:bean diets studied, need to be improved in relation to both quality and quantity of protein.

Introduction

Corn and beans constitute the basic foods in the Latin American diet, especially among the Central American populations [5]. This circumstance has promoted an interest in learning about their nutritional properties individually as well as in combined form [4, 6]. Likewise, much interest has developed in determining the optimum nutritional ratio of consumption between the two foods. This ratio has been established as 2.6:1, which corresponds to a diet constituted by 72 parts corn and 28 parts beans [5].

Comparing these data with actual intakes, a marked imbalance is observed which may be particularly critical in relation to the nutrition of children who, as is well known, constitute the most vulnerable population group [9]. Populations of Guatemala, El Salvador and Honduras consume, on the average, ratios of 7.3, 7.1 and 7.2, respectively, which correspond to an approximate intake of 87 parts corn and 13 parts beans.

It may be stated that, in general, when the rate of consumption of a mixture of corn and beans is closer to the optimum portion previously indicated, the implications will be favorable to the nutritional state of the populations which obtain a high percentage of their nutrients from these two foods. The mixtures, however, even in the optimum proportions, have a low caloric density and a low protein concentration [1]. Such disadvantages could be obviated through an increased intake, which would provide the necessary calories and protein level to maintain an adequate nutritional status within the individual. In this respect, Arroyave [2] reported that four children, between the ages of 1 and 3 yrs., fed a corn:bean diet, in a 70:30

*INCAP Publication I-1144

Qual Plant Plant Foods Hum Nutr 30:145–153 (1980) 0377–3205/80/0302–0145 $01.35.

ratio by weight, were able to meet their protein and calorie needs. Each of the diet constituents supplied 50% of the total protein. It must be kept in mind that these results were obtained in a metabolic ward under completely controlled conditions. On the other hand, Murillo et al. [10] working with dogs, pointed out that such diets were too bulky for the weight and size of the animals. The dogs were unable to fulfill their nutritional needs, since their intakes were limited by their gastric capacity.

The present study had, as the main objective, to determine whether mixtures 70:30 and 87:13 of corn and beans were capable of satisfying the nutritional needs of growing pigs. It was also considered of interest to study the influence of different groups of nutrients on the efficiency of utilization and the consumption of such diets. Growing pigs were used as the experimental animals because of their gastric capacity and digestive performance.

Materials and Methods

Commercial precooked black beans and white corn flour were used to formulate the mixtures. The flours were mixed in proportions of 87:13 and 70:30 corn:beans, respectively. Six treatments were designed from each mixture by adding no nutrients to the mixtures, and by adding groups of nutrients to be studied, which were: a) vitamin mixture, 0.5%[1]; b) mineral mixture[2], 3% [11]; c) cottonseed oil, 3.5%, as a calorie source; d) L-lysine HCl, 0.3%; methionine, 0.3%; and tryptophan, 0.1%, and, for the complete treatment, all of the above nutrients to each of the two mixtures in the appropriate concentration. A control diet was prepared, based on corn (65%) and soybean meal (25%), which was adequate for fulfilling the nutritional requirements of the animals. Total protein content of the original mixtures as well as those utilized in each treatment was determined (Association of Official Agricultural Chemists [3]). The 87:13 and 70:30 corn: bean mixtures contained 9.4 and 12.0% protein, respectively, while the control diet contained 18.0% protein.

Five-week-old Landrace pigs were used. The animals were previously vaccinated, deparasited and fed a basal diet of soybean and corn for a week. Four animals were then assigned per treatment, 2 male and 2 female, taking care that the total initial weight between groups was not different by more than 1 kg. The animals were housed in individual pens with cement floors. Each pen was provided with individual feed and drinking troughs. Water as well as the experimental rations were given *ad libitum* during the 12 weeks of the experiment. During this period, weight and feed intake data were obtained weekly in order to determine any weight or consumption changes, and also to calculate feed efficiency at the end of the study.

The results obtained were statistically analyzed to establish the effects and interactions considered useful for the final interpretation of the data [7, 11].

Results

The average weight gain per animal during the 12-week experimental period is shown in Table 1. It can be observed that the highest weight gains were observed for the control diet (54.9 kg). The difference in weight was statistically different between the control and the other experimental groups. The complete diets with mixtures 87:13 and 70:30 resulted in increases of 35 and 37 kg, respectively, which are also statistically higher than those obtained with diets lacking any individual group of nutrients. Even when the treatments derived from the mixture 70:30 do not show statistical differences, when compared to those derived from the 87:13 mixture, the general tendency is for higher values to be present. It can also be observed that in both mixtures performance, with respect to weight gain, is similar. The lowest value was obtained in both cases with the diet lacking all the groups of nutrients; this value was 2.4 kg for the 87 : 13 and 10.9 kg for the 70 : 30. In general terms, the better response to addition of individual groups of nutrients was obtained when only minerals were added. For the 70:30 mixture, only a weight gain of 17.9 kg was observed and for the 87:13 mixture, a weight gain of 14.6 kg, the latter value was slightly lower than the gain (14.8 kg) obtained when amino acids were added to the 87:13 mixture.

The addition of calories resulted in a very low response with the 87:13 mixture (6.0 kg), while with the 70:30 mixture a weight increase of 8.6 kg was observed which is inferior to that obtained with the 70:30 mixture diet without the addition of any nutrient (10.9 kg). The diet supplemented with amino acids was more effective in the case of the 87:13 mixture, with a weight gain of 14.75 kg, while with the 70 : 30 mixture, the increase in weight was 13.63 kg.

The average consumption per animal during the experimental period is shown in Table 2. The results are similar to those observed for weight gain (to which consumption is related). The consumption of the control diet of

Table 1. Average weight gains of experimental pigs fed corn and bean diets in 87:13 and 70:30 ratios, under different treatments

Dietary treatment	kg/12 weeks 87:13	kg/12 weeks 70:30
-----	2.35 ± 1.6* (d)	10.88 ± 1.9* (c, d)
Amino acids**	14.75 ± 1.2 (c, d)	13.63 ± 1.9 (c, d)
Vitamins	8.50 ± 1.9 (c, d)	15.88 ± 1.8 (c, d)
Minerals	14.63 ± 6.9 (c, d)	17.88 ± 5.8 (c)
Calories	6.00 ± 2.3 (c, d)	8.63 ± 3.6 (c, d)
Complete diet	35.00 ± 4.7 (b)	37.00 ± 6.5 (b)
Control	54.88 ± 3.6 (a)	

Different letters indicate statistically significant difference ($P < 0.05$)

*Standard error

**Lysine, methionine and tryptophan

Table 2. Average feed intakes of pigs fed a corn:bean mixture in 87:13 and 70:30 ratios, under different treatments

Dietary treatment	kg/12 weeks 87:13	kg/12 weeks 70:30
	47.73 ± 3.7* (e)	63.75 ± 2.6* (e)
Amino acids**	78.48 ± 2.4 (e)	73.33 ± 2.3 (e)
Vitamins	64.98 ± 3.3 (e)	78.30 ± 2.7 (e)
Minerals	83.93 ± 9.6 (b, c)	86.78 ± 7.0 (b, c)
Calories	54.50 ± 0.9 (e)	60.53 ± 3.9 (e)
Complete diet	118.42 ± 5.5 (b)	117.45 ± 8.0 (b)
Control	157.75 ± 2.1 (a)	

Different letters indicate statistically significant differences ($P < 0.05$)
*Standard error
**Lysine, methionine and tryptophan

157.8 kg is statistically higher when compared to the intakes induced by each one of the treatments derived from both mixtures. The complete diets, i.e., those containing all nutrients, resulted in higher intakes when compared to the rest of the treatments, 118.4 kg and 117.5 kg for the 87:13 and 70:30 mixtures, respectively. With this exception, in both mixtures the addition of minerals resulted in the highest intakes, with values of 83.9 kg and 86.8 kg for the 87:13 and 70:30 mixtures, respectively. With the diets supplemented with amino acids, the consumption of the 87:13 mixture was 78.5 kg and for the 70:30 mixture, 73.3 kg. The addition of vitamins resulted in a consumption of 78.3 kg and 64.9 kg for the 70:30 and 87:13 mixtures, respectively. As for calories, the consumption was also higher for the 70:30 mixtures with 60.5 kg, against 54.5 kg induced by the 87:13 mixture to which calories were added. The statistical analysis of the results relating weight gain and feed consumption did not show significant differences due to sex.

Table 3 shows the daily weight gains observed for the different diets and their levels of adequacy, as compared to the control diet. The most adequate gains were for the complete diets derived from the two mixtures. However, these only represented 64% and 68% of the weight gains obtained with the control diet. The weight gain for the 87:13 mixture without any additive was only 4% of the gains observed for the control diet, while for the 70:30 mixture alone, it is only 18%.

Table 4 shows the feed efficiency of the diets. With the exception of the diet based on the 70:30 mixture supplemented with amino acids, the 70:30 mixture diets had improved feed efficiency values for all treatments when compared to the diets in which corn and beans were fed in an 87:13 ratio. The largest difference between treatments for the two mixtures was observed between those diets lacking any of the complementary nutrients, with values of 20.3 for the 87:13 mixture and 5.9 for the 70:30 mixture. The smallest differences were observed between mixtures for the diets which were supplemented with amino acids and with the complete diets (all nutrients added).

Table 3. Daily adequacy of weight gains in young pigs fed corn and beans mixtures in 87:13 and 70:30 ratios, under different treatments

Dietary treatment	87:13		70:30	
	Weight gain kg/day	Adequacy %*	Weight gain kg/day	Adequacy %*
------	0.027	4	0.119	18
Amino acids**	0.175	27	0.162	25
Vitamins	0.101	16	0.188	29
Minerals	0.174	27	0.212	33
Calories	0.071	11	0.102	16
Complete diet	0.416	64	0.440	68
Control	0.652	100	0.652	100

$$*\text{Adequacy} = \frac{\text{Weight gain experimental diet}}{\text{Weight gain control diet}} \times 100$$

**Lysine, methionine and tryptophan

Table 5 shows the intake levels of amino acids provided by each of the diets and their adequacy. These values were calculated from the average daily consumption of the two complete mixtures, and for the diets to which amino acids were added, from the amounts supplied by supplementation with lysine, methionine and tryptophan. Analytical amino acid values of the ingredients were determined in our laboratories, while the daily needs (requirements) were obtained from NRC tables.[3]

Mixture 87:13 shows an adequacy of 84% for lysine, 86% for isoleucine, and 73% for threonine. On the other hand, the 70:30 mixture shows an adequacy slightly low only for threonine (92%). It can also be observed that the leucine:isoleucine and leucine:valine ratios (even though better in the 70:30 mixture) were high when compared to the ratio in which these amino acids should be found, according to the requirements of the young pig. For example, it was found that in the case of the control diet, the ratios of leucine:valine and leucine:isoleucine were 1.8 in both cases.

Table 4. Feed conversion* values from young pigs fed corn and bean mixtures subjected to different treatments**

Dietary treatment	Feed efficiency	
	87:13	70:30
------	20.3	5.9
Amino acids***	5.3	5.4
Vitamins	7.7	5.0
Minerals	5.7	4.9
Calories	9.1	6.9
Complete diet	3.4	3.2
Control	2.9	

$$*\text{Feed efficiency} = \frac{\text{Feed consumption}}{\text{Weight gain}}$$

**During a 12-week period

***Lysine, methionine and tryptophan

Table 5. Content and adequacy of the intakes of amino acids from corn and beans mixture

Amino acids	Daily needs g/day	87:13		70:30		Control	
		Intake g/day	Adequacy %	Intake g/day	Adequacy %	Intake g/day	Adequacy %
Arginine	2.8	5.2	186	7.6	271	12.5	446
Histidine	2.5	2.6	104	3.4	136	4.8	192
Isoleucine	7.0	6.0	86	8.4	120	10.8	154
Leucine	8.4	14.2	169	16.9	201	20.4	243
Lysine	9.8	8.2	84	11.4	116	10.8	110
Methionine + Cystine	7.0	7.2	103	8.5	121	6.6	94
Phenylalanine + Tyrosine	7.0	11.8	169	14.2	203	19.2	274
Threonine	6.3	4.6	73	5.8	92	8.3	132
Tryptophan	1.8	2.0	111	2.5	139	2.4	133
Valine	6.0	6.4	91	8.8	126	11.0	157
Leucine: Isoleucine	1.2	2.4		2.2		1.8	
Leucine:Valine	1.2	2.0		1.9		1.8	

Discussion

The results obtained show the inability of the mixture of corn and beans studied to fulfill the nutritional requirements of the animals. In spite of the stimulation of intake levels of the mixtures induced by the presence of complementary nutrients, the intakes were not enough to provide the nutrients required for a growth similar to that obtained with the control diet. Possibly, the gastric capacity is not the only limiting factor, since the animals fed the control diet consumed 33% more feed than those fed the 87:13 and 70:30 (corn:beans) mixtures.

Disregarding the gastric capacity as a possible limiting factor, the low consumption could be attributed to a change in the mechanism which controls appetite, probably due to the deficiency in quality and quantity in the mixtures. The results suggest, however, that the quality of the protein is the most important factor. When the intakes of the two mixtures without any added nutrients are compared, the animals fed the 70:30 mixture consumed 34% more than those fed the 87:13 mixture. However, when both mixtures were supplemented with amino acids, the animals fed the 87:13 mixture surpassed by 7% the consumption of the animals fed the 70:30 mixture. This effect can only be attributed to the improvement in the quality of the protein, since it is the only comparative variable. When the two original mixtures were supplemented with different groups of nutrients (other than amino acids), the consumption of the animals was always higher for the 70:30 mixture. However, when the two mixtures with all nutrients included were offered and duly supplemented with amino acids, the intake of the 87:13 mixture was again 0.8% higher than that

obtained with the 70:30 mixture. These results corroborate the decisive influence of protein quality on the consumption of the mixtures and, therefore, on the mechanism controlling appetite.

When the consumption of the complete mixtures is compared with that of the control diet, differences due to quantity and quality of protein are also observed, since the control samples contain 18% protein against 9.4% supplied by the 87:13 mixture and 12% by the 70:30 mixture. As for quality, the 87:13 mixture showed lysine, isoleucine, and threonine deficiencies. The 70:30 mixture was deficient in threonine. This aspect becomes more significant if one takes into account the low digestibility of the mixtures. On the other hand, the leucine:valine and leucine:isoleucine ratios, even though better in the 70:30 mixture, are still very high for both mixtures. Although these differences are important, protein digestibility probably also plays a significant role, due to the low digestibility of beans [5]. Together, these considerations can explain the refusal of the animals to eat higher amounts of this type of food.

It has been suggested that populations subsisting on diets based on corn and beans could derive from these foods the protein as well as the calories necessary to maintain an adequate nutritional state, if they would increase their intake. If so, then the availability of these foods would be the most critical factor. Taking into account that rations are given *ad libitum*, that is without limitation as far as availability or time effects are concerned, this point may be questioned and should be studied in detail. On the other hand, the results presented confirm the importance of total nutrients in the diet, in relation to protein utilization and the need of complementary nutrients when the quality of the protein is improved through supplementation of the deficient amino acid. The addition of calories in an isolated form does not lead to the improvement expected in the utilization of the mixtures. Also, on this point, it would seem that the quality and quantity of protein plays an important role, since the animals to which the 87:13 mixture was administered, with only calories added, gained 6.0 kg against 8.6 kg obtained with the 70:30 mixture. The best response, however, was due to the interaction of amino acids, vitamins and minerals, which promoted the best utilization of the protein and calories supplied by the mixtures.

It is worthwhile to point out the relative importance of minerals over the other groups of nutrients, when the 70:30 mixture, which supplied a higher quantity and quality of protein, was offered. Also, the results with the 87:13 mixture, when minerals alone were added, were comparable to those obtained when protein quality was improved by addition of amino acids, and were definitely higher than those obtained by the addition of only vitamins and calories.

Therefore, the results presented indicate that an increase in bean consumption that will raise the ratio of consumption of beans and corn to the nutritionally optimal ratio is a desirable measure, as is the supplementation with

the deficient amino acids in the mixtures, and the simultaneous correction of the deficiencies in minerals and vitamins. However, actions which are intended to fulfill this purpose will have an incomplete impact in the solution of the nutritional problem, since, as was demonstrated, diets which fulfill these requirements are unable to supply the caloric or protein requirements necessary for the normal growth of the animal. Therefore, policies and programs which include basic grains, which are frequent in our media, are scarcely effective in improving the nutritional status of the population. Only programs whose approach is to furnish a balanced food system would be able to fulfill this purpose.

Summary

The present study was performed to determine whether 70:30 and 87:13 mixtures of corn and common beans, respectively, were capable of satisfying the nutritional needs of 5-week-old pigs fed *ad libitum*. It was also considered of interest to study the influence of different groups of nutrients such as vitamins, minerals, limiting amino acids and calories, added individually or together, on growth performance and efficiency of feed utilization and diet consumption.

After a 12-week experimental period it was found, from individual animal measurements, that an increase in bean intake that will raise the ratio of consumption from 13:87 to 30:70 (beans:corn), the latter ration considered optimum, is a desirable measure, as is the simultaneous supplementation with the limiting amino acids, vitamins, minerals and calories. Addition of individual groups of nutrients resulted in partial improvement in animal performance and diet utilization.

Even when fully supplemented with all nutrients, neither of the two mixtures was capable of inducing a growth performance equal to that obtained with the control corn:soya diet. The results confirm the importance of total nutrients in the diet to obtain increased efficiency of protein utilization. Furthermore, it would appear that, for corn and beans diets to be effective, they need to be improved in terms of both quality and quantity of protein.

Acknowledgment. This research was carried out with funds from the Research Corporation, New York, NY (grant-in-aid INCAP no. PN-740).

Notes

1. Vitamin D_3: 0.375%; vitamin A: 1.200%; vitamin B_{12}: 0.440%; D-calcium pantothenate: 0.800%; niacin: 1.500%; riboflavine: 0.316%; starch: 95.369%.
2. Calcium: 24%; phosphorus: 12%; salt: 18%; iodine: 0.009%; iron: 0.2%; copper: 0.01%; cobalt: 0.01%; manganese: 0.006%; zinc: 0.01%.
3. National Academy of Sciences (1968) Nutrient requirements of swine, 6th ed. National Academy of Sciences–National Research Council, Washington, D.C. (Publication 1599).

References

1. Araya H & G Arroyave (1979) Relación del contenido energético proveniente de grasas y de proteínas como indicador de la potencialidad energético-proteínica de las dietas de poblaciones. Arch Latimoamer Nutr 29: 103–112
2. Arroyave G (1973) Protein requirements of children of preschool age: corn: bean diets. Instituto de Nutrición de Centro América y Panamá, Guatemala. Unpublished data
3. Association of Official Agricultural Chemists (1970) Official Methods of Analysis of the Association of Official Agricultural Chemists, Washington, DC
4. Bressani R & LG Elías (1968) Processed vegetable mixtures for human consumption in developing countries. Adv Food Res 16:1
5. Bressani R & LG Elías (1974) Legume foods. In: New Protein Foods, AM Altschul ed pp 230–297 Academic Press, New York, NY
6. Bressani R, LG Elías & DA Navarrete (1961) Nutritive value of Central American beans. IV The essential amino acid content of samples of black beans, red beans, rice beans, and cowpeas of Guatamala. J Food Sci 26:525–528
7. Dencon DB (1955) Multiple range and multiple F tests. Biometrics 11:1–42
8. Elías LG & R Bressani (1974) Nutritional factors affecting the consumption of leguminous seeds. Arch Latinoamer Nutr 24:365–378
9. Flores Marina R Bressani & LG Elias (1973) Factors and tactics influencing consumer food habits and patterns. In: Potentials of Field Beans and Other Legumes in Latin America pp 88–114, Centro Internacional de Agricultura Tropical Cali Colombia. (CIAT Series Saminar No 2E)
10. Murillo B, MT Cabezas & R Bressani (1974) Influencia de la densidad calórica sobre la utilización de la proteína en dietas elaboradas a base de maíz y frijol. Arch Latinoamer Nutr 24: 223–241
11. Snedecor GW & WG Cochran (1967) Statistical Methods. Sixth Edition. 593 p The Iowa State University Press, Ames, Iowa