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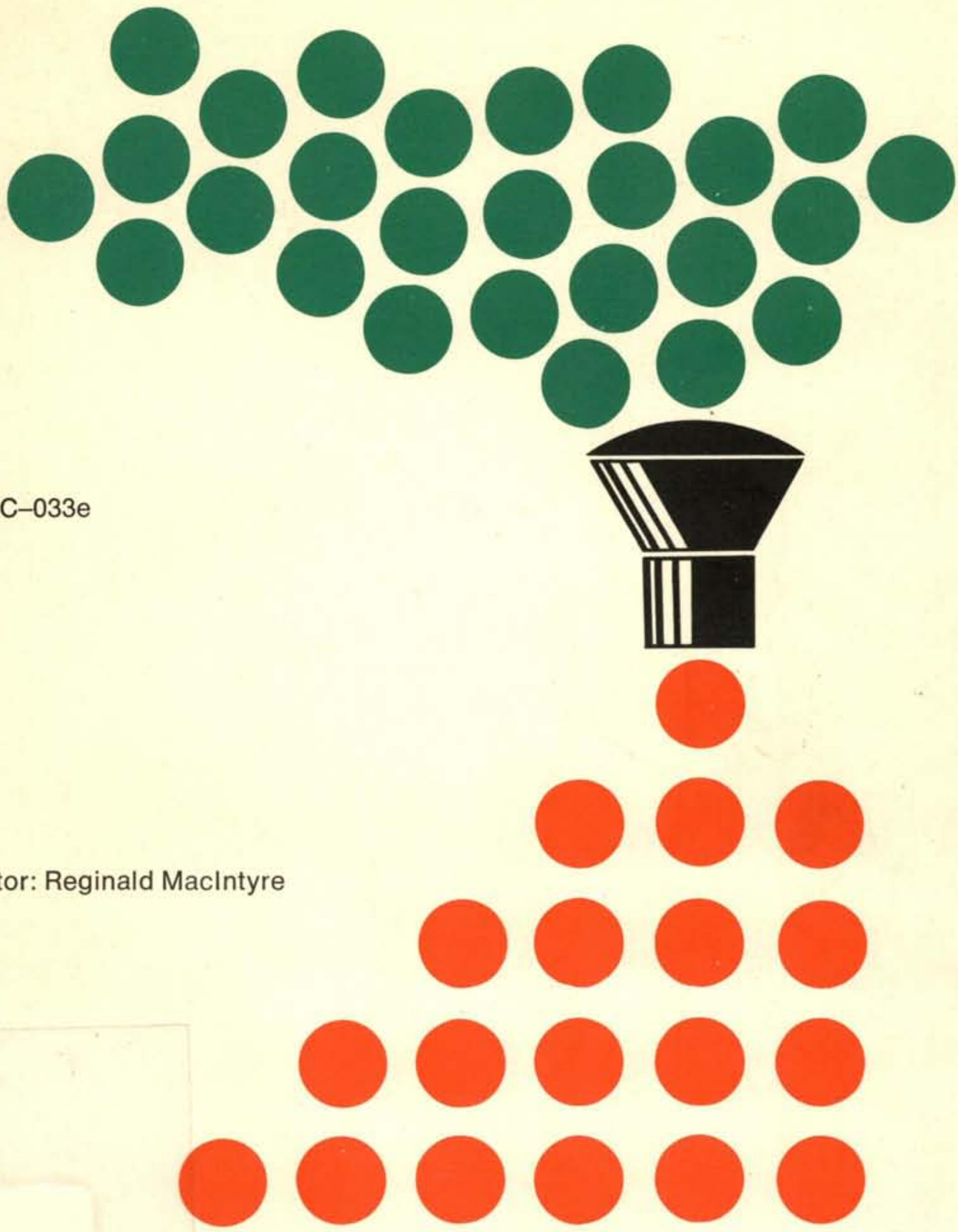

IDRC–033e

Editor: Reginald MacIntyre

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Sponsored by the International Development Research Centre
in cooperation with the
International Union of Food Science and Technology

ISBN: 0-88936-038-3
UDC: 631:641

Postal Address: Box 8500, Ottawa, Canada K1G 3H9
Head Office: 60 Queen St., Ottawa
Microfiche Edition $1.

Contents

Improvement of Crops and their Relationship to Nutrition and Food Science Technology in the Semi-Arid Tropics

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Abstract In the semi-arid tropics water and not land is the limiting factor in crop production. The dry season lasts between 5 and 10 months. Sorghum, pearl millet, pigeon pea and chickpea are the most important cereal and pulse crops of the region. Low yields, instability of production, low nutritional quality of the existing varieties, and high disease and pest susceptibility are the serious problems. The International Crops Research Institute for the Semi-Arid Tropics seeks solutions to these problems particularly in increasing yield and stabilizing production under rain-fed conditions of the semi-arid tropics. Interdisciplinary research programs of biological scientists, physical scientists, engineers, nutritionists, and economists have been started. Important steps toward these goals include: collection, evaluation, and utilization of the world's resources of germ plasm collected from many sources; development of varieties of composites or hybrids with high yield potential, disease resistance, high lysine, and high protein efficiency ratio; screening and evaluation of varieties and promising lines for high nutritional value; improvement in drought tolerance and environmental screening and stability characteristics of the variety; and development of plant morphology to make the varieties suitable for intercropping, companion cropping, and relay cropping.

Résumé C'est l'eau et non la terre qui constitue le principal facteur limitant la production agricole dans les régions tropicales semi-arides. Le sorgho, le mil à chandelles, le pois cajan et le pois chiche constituent les céréales et les légumineuses principales de cette région, dont elles servent à mesurer la productivité. La saison sèche dure de 5 à 10 mois. La faiblesse des rendements, l'instabilité de la production, la faible valeur nutritive des variétés cultivées, ainsi que la grande sensibilité de celles-ci aux maladies et aux parasites constituent autant de problèmes sérieux. L'Institut International de Recherches sur les Cultures dans les Régions Tropicales Semi-Arides se penche sur les solutions à apporter à ces difficultés, notamment sur celles de l'accroissement des rendements et de la stabilisation de la production dans les conditions de culture pluviale qui sont celles de ces régions tropicales semi-arides. Il a mis en oeuvre des programmes de recherches interdisciplinaires auxquels participent des biologistes, des physiciens, des techniciens, des nutritionistes et des économistes. La poursuite des objectifs prévus comporte les étapes suivantes: Rassemblement, évaluation et utilisation du matériel génétique provenant de nombreuses sources réparties à travers le monde entier; création de variétés d'hybrides à potentiel de production élevé, résistants aux maladies, à forte teneur en lysine et dotés d'un fort coefficient d'efficacité protéique; sélection et évaluation de variétés et de lignées prometteuses du fait de leur haute valeur nutritive; amélioration de la résistance à la sécheresse, de l'adaptabilité et de la stabilité de ces variétés; obtention de variétés dont la morphologie convienne à la culture en intercalaire, à la culture mixte et aux cultures d'appoint.

THE problem of food shortage and malnutrition is becoming more acute as the population increases. The problem is most acute in Africa, Asia, and Latin America, particularly in the arid and semi-arid regions. It is aggravated during droughts and aberrant weather, which affect the success of food crops. There is considerable scope for increasing production of food crops in the tropics.

The staple cereal diet in the semi-arid tropics consists of sorghum and millets, and the main source of protein is the grain legumes, particularly pigeon pea and chickpea. This is certainly true in the semi-arid tropics of Africa and the Far East, particularly India. FAO statistics for 1972 (Table 1) show 49 and 34% of the area under cereals is devoted to cultivation of sorghum and millets in Africa and India, respectively. The major areas of the world under pigeon pea and chickpea cultivation is also in India: where 90% of the world's area under pigeon pea and 76% under chickpea. Though the area under these crops is fairly high, the yields are very low (Table 1).

Out of a total production of 23.4 million tons of sorghum (produced as human food grains) in the developing countries, 33% comes from India and 37% from Africa. The sorghums and millets provide not only the calories but also about 70% of the protein for the population. The balance of protein needs is provided mostly by grain legumes. In food grain legumes, 97% of chickpea and 96.4% of pigeon pea are provided by the developing countries. The edible grain legumes have exceptional potential for alleviating the malnutrition in the tropics because of their wide adaptation, low fertilizer requirements, multiple and high quality of protein.

When we consider that 38% of the world's population lives in the tropics and Southeast Asia including India, it is clear that to meet the food needs of the world sorghum, millets, pigeon pea and chickpea are most important crops. ICRISAT is therefore concentrating its efforts on these species, with pressing demands to study groundnuts since they also represent an important source of protein in the semi-arid regions of the world.

Troll's classification is used to define semi-arid regions: 5–10 arid dry months, and 2–7 humid months with erratic distribution of rain. In certain areas of this region sorghum and millets occupy a favourable competitive position in the present food production system primarily due to distribution and amount of precipitation and evapotranspiration patterns. On the basis of these criteria of climate and crops the semi-arid and tropical region comprises a 400–900 km wide strip across Thailand, Burma, India and Pakistan, a 900 km wide belt across Africa from Senegal to Kenya, a 1300 km wide belt from Angola to southern Tanzania. Scattered areas from north-east Brazil to central Mexico, northern Argentina and northern Australia also fall in this category. Generally the region has 500 to 1500 mm of rainfall. Brief droughts may often occur during the monsoon season making agriculture unstable and frequently unproductive.

Problems

The main problems of crop production in the region are the following: (1) long dry periods alternating with short wet periods of low rainfall; (2) erratic distribution of rainfall with occasional occurrence of droughty periods; (3) occurrence of black, red, and sandy soils, which offer numerous problems of soil and water management; (4) predominance of rainfed agriculture due to inadequate supply of available water for irrigation; (5) low yields of sorghum, millets, and grain leg-

TABLE 1. Area, production, and yield of sorghum, millets, pigeon pea, and chickpea in different regions of the world, 1972.

Region	Total under cereals	Millets	Sorghum	Total of sorghum & millets expressed as % of total under cereals in the region	Pigeon pea	Chickpea	Total of pigeon pea & chickpea expressed as % of total under food legumes in the region
1	2	3	4	5	6	7	8
		(A) Area under the crop (*million ha*)					
World	699	65.00	39.9	15.0	2.587	10.54	23.7
Developing countries							
Africa[a]	54	13.80	10.3	44.0	0.147	0.50	6.3
Latin America	46	0.40	2.8	7.0	0.050	0.23	4.0
Near East	36	0.99	3.5	12.0	–	0.26	2.0
Far East[b]	152	17.60	16.6	22.0	2.390	9.23	43.0
India	96	16.50	16.0	34.0	2.310	8.00	48.6
Centrally planned	263	32.20	0.11	12.2	–	–	–
		(B) Production (*million tons*)					
World	1275	43.0	46.7	7.0	1.72	6.72	19.7
Developing countries							
Africa[a]	46	8.5	7.5	35.0	0.07	0.35	7.1
Latin America	67	0.33	5.0	8.0	0.041	0.20	5.1
Near East	48	1.4	3.3	9.8	–	0.28	15.3
Far East[b]	206	8.2	7.6	7.6	1.61	5.70	59.7
India	107	7.6	7.2	14.0	1.57	5.10	62.6
Centrally planned	4560	24.5	0.13	5.0	–	–	–
		(C) Average yield per hectare (*kg*)					
World		600	1170		665	627	
Developing countries							
Africa[a]		612	733		483	612	
Latin America		815	1735		324	804	
Near East		1434	945		–	1000	
Far East[b]		464	460		673	625	
India		461	450		681	636	
Centrally planned		761	1099				

Source: FAO Production Year Book, Vol. 26, 1972.

[a]Africa excluding South Africa.
[b]Far East includes India.

umes, which form the main food of the people; (6) poor and unbalanced human diet due to inadequacy of proteins and deficiency of certain amino acids like lysine, methionine, cystine, etc.; (7) inadequate agricultural research base in the region.

ICRISAT

The International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) was set up in July 1972 with international financial support. ICRISAT focuses attention on the development of technology for increasing production and increasing nutritional quality of sorghum, pearl millet, chickpea and pigeon pea for cultivation under rain-fed conditions in the semi-arid tropics. Groundnuts may be included in its research program since it is one of the important crops and fits into the cropping system. One of the most important responsibilities of ICRISAT is to develop farming systems which will help to increase and stabilize agricultural production by optimizing the use of natural and human resources. To meet these objectives, ICRISAT must develop training and outreach programs throughout the semi-arid regions. Steps have already been taken to identify suitable centres for outreach activities in Africa and Latin America.

Sorghum & Millets

Sorghum and millets are the most widespread cereal crops grown in the semi-arid tropics. Pearl millet is the most dominant crop grown in comparatively drier conditions on lighter soils. Sorghum is preferred on heavier soils having a higher moisture retention capacity.

In the last decade great strides have been made in the improvement of grain sorghum. In the developed countries sorghum is produced for animal feed and yields are high; yields produced for human food are low. In countries like India, a number of hybrids which yield 2–5 tons/ha under rain-fed conditions and proper management of soil and water have been introduced but still there is no breakthrough in production. The most serious problems are inadequate adaptability and higher susceptibility of the varieties or hybrids to diseases and pests; poor keeping-quality of the grain; lower acceptability of the grain and flour; high cost and unsatisfactory supply of hybrid seed; and unavailability of better varieties and hybrids for the dry season.

The International Symposium on Sorghum in the 1970s held in India highlighted these aspects and discussed the approaches for research on these problems. The research work undertaken at ICRISAT is attempting to overcome these defects and develop varieties or hybrids suited to different environmental conditions. Development of varieties and resistant to important diseases like smut, downy mildew, and blight, and pests like sorghum shootfly, stem-borer, and midge will bring about a revolution in sorghum production. We still do not know the desirable morphology of an efficient sorghum plant. Grain sorghum occupies a prominent place in the food of the poor peoples in developing countries, and it occupies the fourth place in the cereal foods of the world but first in the semi-arid tropics. However its nutritional quality is not very good, and consumption of large quantities may cause malnutrition-related diseases in man. According to Gopalan and Srikantia (1960) the presence of a relatively high concentration of leucine and/or imbalance of leucine:isoleucine ratio in sorghum is responsible for pellagra in a population subsisting on sorghum.

It is, however, realized that the acceptable quality of grain is a very important characteristic. The plant breeders are very conscious of the necessity of upgrading the quality of the grain. A worldwide search is being made for a germ plasm possessing disease and pest resistance and better grain quality. An outstanding discovery has been made by the Purdue University group in locating two high-protein and high-lysine varieties of sorghum from Ethiopia. Rameshwar Sing and John Axtell (1973) analyzed these varieties locally called *Marchuke* (IS 11167) and *Wetet-Begunche* (IS 11758). The former in local Ethiopian language means "honey spurts out" and the latter denotes "milk in the mouth." Marchuke is grown at higher elevations. The main characteristics of these varieties are high protein, high lysine, and high oil and fat and low tannin content (Table 2).

Singh and Axtell have also reported that high lysine gene alters the amino acid pattern in hl. hl. hl. endosperm tissue in relation to normal endosperm checks. The major changes

Evaluating sorghum germ plasm.

are increased lysine, arginine, aspartic acid, glycine and tryptophan and decreased content of glutamic acid, proline, and leucine compared to normal endosperm tissue.

The farmers in Ethiopia have been growing these varieties for centuries, not as pure crops but as an admixture with the normal sorghum varieties which give higher yields than the special purpose or novelty varieties. The farmers start harvesting them at milk ripe stage and eat the roasted grain. When the crop is fully ripe some of the grain of the varieties is also harvested along with the rest and reprocessed together. These varieties offer a great promise for upgrading the nutritional quality of sorghum, but it is not envisioned that they

TABLE 2. Main characteristics of Marchuke and Wetet-Begunche.

	High lysine lines		
Character	IS 11167 (Marchuke)	IS 11758 (Wetet-Begunche)	Normal sorghum
Protein (%)	15.70	17.20	12.70
Lysine (*g/100 g. protein*) in proteins	3.33	3.13	2.05
Lysine % in sample	0.524	0.540	0.258
Oil %	5.81	6.61	3.32
Sucrose %	3.08	2.61	1.03
Catachin equivalent (Tannin)	0.34	0.37	0.38

*Data courtesy of Rameshwar Singh and John Axtell can replace the normal varieties of high yield potential. Axtell and his associates have observed that as compared to normal sorghums the high lysine lines gave nearly 2 to 3 times more grain in weight of weanling rats. Thus there are great prospects of upgrading the nutritive value of the sorghum through the newly discovered varieties. They are also excellent sources of special foods including baby foods, and offer a means of upgrading the cereal/pulse diet particularly for the poor sections of the population. ICRISAT is making use of this germ plasm in evolving higher-yielding and nutritionally superior varieties through genetic engineering. Purdue University is doing pioneering work on this problem and ICRISAT is collaborating with them.

Upgrading the quality of protein and lysine content in sorghum is one of the methods of improving the nutrition of the poor people, but balancing the diet by supplementation with grain legumes or pulses of high quality is another. The fall in production of pulses and resulting high price further aggravated the protein- and lysine-deficiency diseases. Thus, while the emphasis for better protein and high lysine varieties will be very useful, more rewarding results may be achieved by increasing the yield potential of pulses, and their nutritive value, since they are conventional supplements for cereals particularly in countries like India. ICRISAT scientists are continuing to emphasize improvement of sorghum yield potential consistent with quality, and do not wish to sacrifice yield at the cost of quality. We are more interested in harvesting markedly larger amounts of calories, proteins, and amino acids per hectare than per 100 grain weight.

It is well known that deficiency of plant nutrients not only depresses yield but also lowers quality of the produce. The role of nitrogen, phosphorus, and potassium in this case is also well known but the significant part played by micronutrients like zinc, iron, copper, etc. is not so well appreciated. Indian experience with wheat, rice, sorghum, and chickpea has shown that in a zinc-deficient soil not only the protein content in the grain falls but the lysine content also decreases. The sulphur deficiency likewise causes reduction in sulphur-containing amino acids such as methionine and cystine. Future work at ICRISAT will examine this problem more intensively. Proper nutrition of the plant may solve many of the malnutrition problems.

Under the UNDP Programme on Sorghum and Millets at ICRISAT, an effort will be made to assess the nutritive quality of various varieties in addition to crop improvement. Thus the world germ plasm will be completely analyzed and nutritive value assessed. We plan to analyze about 8000–10,000 samples every year. We feel that there is some germ plasm in inaccessible areas of India, mountain areas of Ethiopia, and other areas of Africa where good germ plasm with some special features may be available. A survey might yield very valuable results.

One other aspect which needs attention is the post-harvest technology of coarse grains like sorghum and millets. These cereals have a low commercial value and have not attracted much attention from the technologists. Moreover, in the developed world they are primarily used as animal feed and not as human food, thus the processing technology is not well developed. However, some work has been done at the Central Food Technological Research Institute, Mysore, showing that by suitable processing excellent tasting products can be made, which may have much appeal even to the developed world. The possibility of extracting oil from varieties with high protein, high lysine, and high fat seems to be very good. In Ethiopia some firms are already considering this possibility for the manufacture of high protein animal feeds after extracting fat and oil from these varieties. In view of the worldwide shortage of vegetable oil this is a promising development. Dr. Hugh Doggett and his group at ICRISAT have assembled about 18,000 lines of the world germ plasm and the elite material from major centres of research in sorghum. They are evaluating and using the germ plasm in an extensive breeding program. The main aim is to develop genetic material which could be useful for plant breeders in different countries for developing varieties and achieving a breakthrough in sorghum production.

Millets

Millets constitute the most important crop of the semi-arid tropics, particularly in the developing countries. Pearl millet is the most important crop. India has the largest area (10 million ha) under this crop in the world. Other important millet-growing countries are Nigeria, Niger, Mali, Chad, and Senegal. Pearl millet, which originated in Africa, forms the poor man's diet and is grown mostly on sandy loam soils and under arid climates. The development of high-yielding hybrids in the last decade has been really a major breakthrough in this crop. The major thrust at ICRISAT on this crop is on the development of hybrids with high-yield potential, downy mildew resistance, and better nutritive quality. Another problem is infection with ergot. This crop, because of its shorter duration, low water requirements and rationing ability, has great potential in the whole of this region. In India, which has nearly 60% of the entire area under pearl millet in the world, next to wheat, there has been a revolution in the production of this crop as a result of introduction of hybrids. At present five hybrids are being cultivated but most of them have succumbed to downy mildew and ergot, which are the biggest menace. Since the susceptibility to these diseases is being contributed by the common male sterile line 23A, an intensive search is under way for disease-resistant male sterile lines, and some have already been identified. We feel that composites and synthetics may have a better chance of succeeding against new races of diseases than hybrids. Our efforts are therefore being directed toward developing varieties as well as hybrids. Three crops of pearl millet can be grown at Hyderabad in a year, which will greatly accelerate the breeding program. At present our germ plasm resources are deficient in African material. A vigorous collection program is planned to make up for this deficiency.

Intensive work on upgrading the quality of pearl millet is under way. In the world germ plasm collection there are some lines with 21% protein compared to 6–8% in normal lines. Efforts are being made to increase the protein content moderately and improve its quality by raising lysine content consistent with high-yield potential. Pearl millet has a high fat content hence high caloric value. However, efforts are to be made to improve its digestibility.

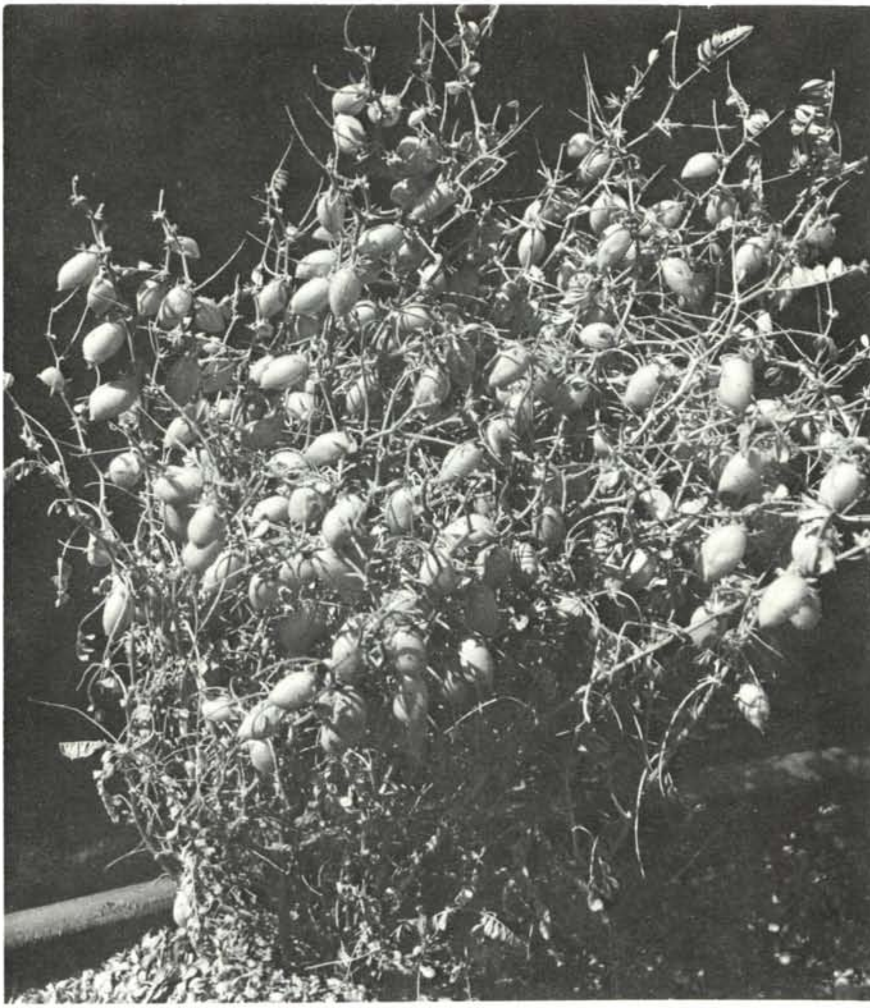
Very little work has been done on nutritional quality and amino acids content in the pearl millet lines. In 1974, we hope to chemically analyze and screen for nutritive quality the world germ plasm which at present consists of 2700 lines.

The technology of processing pearl millet needs further study. Preliminary investigations in the CFTRI at Mysore show that the grain can be processed and many crispy products made from it. It is also a good source of fat which can be profitably extracted. This grain crop has tremendous potential which has yet to be exploited.

Researchers at ICRISAT are developing not only hybrids of high-yield potential and disease resistance but also the composites of different maturity groups. They have identified four maturity groups: (1) early maturity composites (EC), 45 days to heading; (2) medium maturity composites (MC), 45–55 days to heading; (3) late maturity composites (LC), 55 days to heading; and (4) dwarf maturity composites (DC).

Chickpea and Pigeon Pea

The food legumes are the major source of protein and other nutrients in the diet of most people in the semi-arid tropics, and in fact in all the developing countries. Recent statistics show that Southeast Asia, particularly India, and Africa are the main suppliers of these vegetable sources of proteins. Of the food legumes, groundnut contributes 36%, chickpea 16%, and pigeon pea 6.9% to the total production in the tropics. These crops also occupy an important position in cropping patterns, crop rotation, and mixed cropping systems. They represent the most neglected crops and are often grown on marginal soils without much care. Very little research has been done on improving yield potential and nutritional



An elite chickpea variety.

quality. They are rich sources of protein and lysine but not methionine and cystine. They are high in calories (350–570 cal/100 g edible protein) and are good sources of thiamine, nicotinic acid, tocopherol, calcium, iron, and phosphorus. Because of the serious shortage of proteins in the world, and the dominance of chickpea and pigeon pea in the pulses group in the developing countries, ICRISAT has selected these crops for plant improvement research. The distribution of these crops in the top seven countries having the largest area under the crop is given in Table 3.

India has 90% of the world acreage and 91% of the world production of pigeon pea (Table 3), and 76% of the world acreage and 91% of the production of chickpea. The second biggest contributor to both these crops is the African region.

The consumption of chickpea and pigeon pea per day in important pulse-consuming countries is as follows (FAO *statistics*):

Chickpea	Grams/day	Pigeon Pea	Grams/day
Mauritania	23.7	Dominican Republic	14.9
India	20.4	India	8.2
Togo	20.1	Burma	1.6
Ethiopia	16.7	Uganda	5.0
Jordan	6.6	Malawi	3.5

TABLE 3. Distribution of chickpea and pigeon pea.

Region	Area (*thousand hectares*)	Yield (*kg/ha*)	Production (*thousand hectares*)
Chickpea			
India	8027 (76%)	636	5106 (76%)
Pakistan	970	532	516
Ethiopia	302	642	194
Mexico	215	837	180
Spain	145	560	62
Turkey	115	1478	170
Iran	100	500	50
World	1054 (100)	637	6718 (100)
Pigeon Pea			
India	2311 (90%)	681	1574 (91%)
Uganda	90	444	40
Burma	74	405	30
Malawi	35	571	20
Dominican Republic	27	1000	27
Tanzania	22	500	11
Venezuela	11	509	6
World	2587 (100)	665	1720 (100)

FAO also reported that the consumption of pulses has fallen from 75 to 39 g/day due to inadequate supply and high price. This is causing great concern. To make a breakthrough in legume crops all the diverse germ plasm available in the world should be used. At present, ICRISAT has a collection of nearly 8000 lines in pigeon pea and 7562 in chickpea. The collection from Africa and Latin America is extremely inadequate. All the available germ plasm from these countries should be quickly collected and used for developing high-yielding and nutritionally superior varieties. Unlike sorghum and pearl millet whose second and third generations respectively can be taken in a year at Hyderabad, pigeon pea and chickpea is successfully grown only once a year. The question of taking the second generation for expediting the breeding program is very important. In case of chickpea there is a possibility of taking second generation in Lahaul Valley in Himachal Pradesh at an altitude of 10,000–12,000 feet above sea level. The other possibility is in the Middle East (e.g. Lebanon, Iran, Turkey, etc.), but virus diseases may create plant quarantine problems. We are exploring these possibilities to give us two generations of chickpea in a year.

We are also trying to raise the second generation of pigeon pea under irrigation at Hyderabad.

Major Problems in Improvement of Chickpea and Pigeon Pea

Low Yield Potential

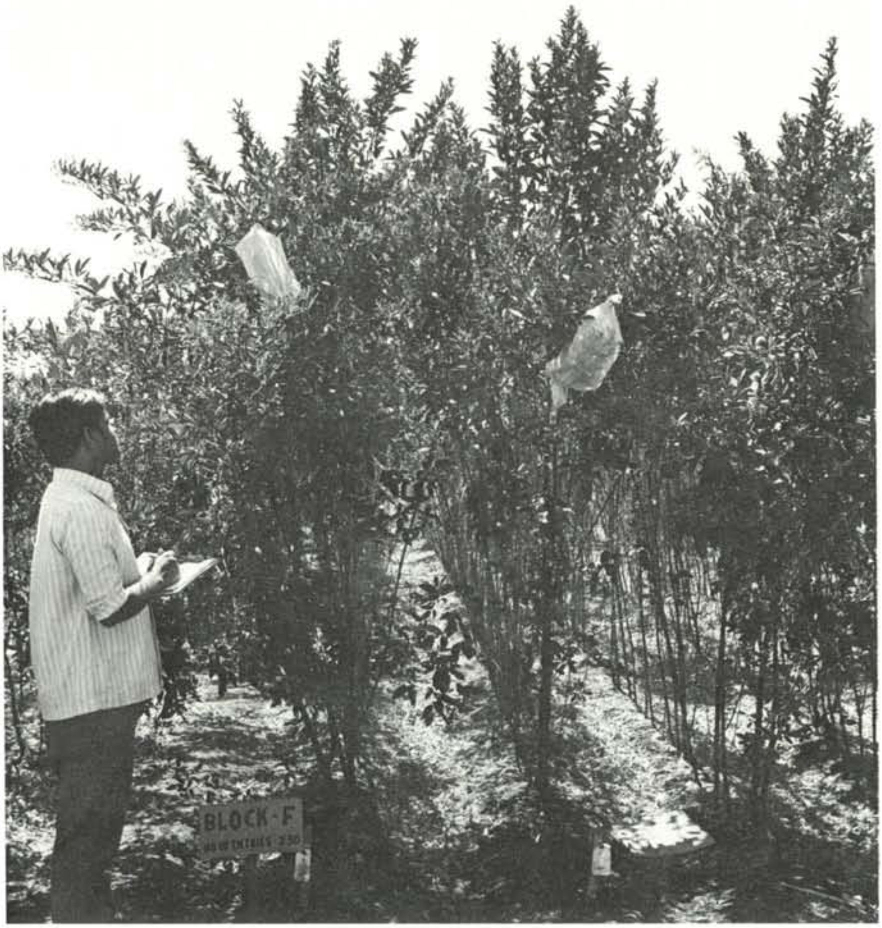
The existing varieties have low yield potential although pigeon pea yields 10–25 q/ha under unirrigated conditions and 40–50 q/ha under irrigated conditions (Ramanujam 1973). Chickpea breeding trials in India have yielded 25–35 q/ha. Even from large-scale trials, chickpea yields of 20–30 q/ha are common. The first objective of the ICRISAT research programs is to improve productivity. Changing the plant architecture genetically and increasing harvest index is the foremost problem. The second objective is the yield stabilization by improving adaptability of the varieties to various environmental extremes.

Resistance to Diseases and Pests

Another ICRISAT objective is to produce disease-resistant varieties. The most serious fungal diseases of chickpea are wilt and blight and in pigeon pea wilt and others. In some countries even viral diseases affect these crops. The pod borer is a serious pest of both crops and reduces yield considerably.

Nutritional Problems

Unlike cereals, so far no food legume varieties have been developed which would be highly responsive to fertilizers, particularly phosphates to which the legumes generally respond. Unless some significant results are achieved, large increases in yield per hectare will not be possible. The nitrogen metabolism in food legumes is not well understood, although at the time of pod filling the nitrogen level in leaves and stems falls to such a low



Comparative study of pearl millet genetic material.

level that the grain formation is seriously affected. Many plant physiologists feel that at this critical stage nitrogen may be a limiting factor. This area requires further investigation. Specific susceptibility to zinc and other micronutrients also needs investigation. Indian experience suggests significant varietal differences.

Genetic improvement of nutrient composition and digestibility

Protein:

Generally both chickpea and pigeon pea have 18–21% protein and there is a good opportunity to increase this level as well as the quality of protein. The higher yield potential should be measured not in terms of dry grain weight but in terms of amount of protein produced per hectare, and its quality.

Amino Acid:

Methionine and cystine are generally the limiting amino acids in the food legumes except for pigeon pea in which tryptophan is also limiting. Thus a concerted effort is necessary to improve the content of these amino acids. Improving sulphur nitrogen and phosphorus content of the grain should help in improving the content of these sulphur-bearing amino acids. Some observations in India show that in the chickpea varieties generally there is an inverse relationship between sulphur content and methionine content, whereas

Evaluating a variety of pigeon pea.

in *Vigna mungo* and *Vigna radiata* application of sulphur increases the methionine content. Very recent studies using radiation techniques have shown that in soils deficient in sulphur, chickpeas also respond similarly to *Vigna Mungo*. More basic studies are needed to understand the problem.

Stepping-up protein content:

Since food legumes are used to supplement cereal foods (which generally have a low lysine content), the lysine content in legumes should be increased to compensate for the deficiency in cereals. Other essential amino acids like threonine, if they become limiting factors in the overall diet, need to be increased in the food legumes to balance the cereal diets. More research is necessary to determine the extent to which the amino acid content can be modified in plants.

The Protein Advisory Group of the UN suggests that certain minerals (zinc, calcium, cerium) and vitamins in the legume grains should also be maintained at the highest possible level. Improvement of productivity, adaptability, and yield stability should be the first priority. Improving the nutritional value of legumes and reducing the concentration of some undesirable constituents (flatulence-producing feature of the chickpea could be lessened by genetic engineering), is next in importance.

Plant type for special purpose

In many countries, particularly in Latin America, Kenya, and Bangladesh, green pods of pigeon peas are used for canning or vegetable purposes. Thus while an effort has to be made for high-yielding and dry, grain-producing varieties the special requirement for canning and vegetable purposes also needs to be met.

Pigeon pea is also well suited for mixed cropping and relay-cropping systems. The plant type and its maturity durations are the most important factors for this purpose.

In India, pigeon pea is generally grown as an intercrop with cereals, particularly sorghum. The varieties in use are generally slow-growing initially and are of long duration (8–9 months). So even with a normal spacing of sorghum and intercropping of pigeon pea, which is often broadcast, the yield of the main crop is not greatly affected. However, pigeon pea does not make normal growth till sorghum is harvested. At ICRISAT, experiments are under way to select types of sorghum, pearl millet, and of pigeon pea which will make ideal combinations for intercropping or companion cropping. Pattern of cropping is also being studied. Paired-row system, compressed rows, and a regular pattern of 3–4 solid rows of the cereal crop with one row of pigeon pea are also being studied. The short plant type with erect growth habits seems promising. Of the cereals, pearl millet may be even more promising than sorghum for companion cropping.

Possibilities of companion cropping of sorghum and pearl millet with soyabean, mung bean (*Vigna radiata*), and relay cropping with chickpea, safflower, and setaria, are also being examined. Plant morphology and length of growing season of the main cereal and of companion or relay crop is very important. Critical plant population beyond which the yield of cereal declines, or the maximum population of the intercrop of the same maturity as the main crop, is very important as it affects the efficient utilization of arable land.

In north India a short-duration variety (120 days) would be ideal for rotation with wheat. Thus the past tradition of cultivating slow-growing and long-duration varieties has to be replaced with shorter-duration but higher-yielding varieties. The germ plasm obtained from Brazil may have high potential for breeding such varieties. Chickpea germ plasm from Ethiopia, the Middle East, and Mexico may be very useful as well for cross-breeding programs.

ICRISAT is making considerable effort to collect germ plasm from all sources We are collaborating with ALAD in Beirut, US Program in Puerto Rico, and All India Co-ordinated Pulse Program in India. Detailed knowledge concerning the genetic, chemical, and nutritional characteristics of these germ plasms will speed up the realization of our objective of developing higher-yielding varieties with better nutritional quality, particularly higher lysine and methionine content.

Rhizobial cultures for grain legumes

Grain legumes are credited with nitrogen fixation, but very little is known regarding the varietal differences. The rhizobial culture for chickpea and pigeon pea have not produced any spectacular results. It is essential to make a basic study of the varietal relationship to nitrogen fixation and identify efficient strains of rhizobial cultures.

Conclusions

The research program for the improvement of crops in the semi-arid tropics must be based on: 1) collection of worldwide germ plasm; 2) development of varieties or hybrids with high yield potential, disease-resistance, and high lysine content, and medium protein content with a high protein efficiency ratio; 3) improvement of drought tolerance and environmental stability characteristics of varieties; and 4) development of plant morphology to make varieties suitable for mixed cropping, companion cropping, intercropping, and relay cropping.

To achieve these objectives, ICRISAT has started a program at Hyderabad and is collaborating with the active research programs in other countries. Financial support is being received from UNDP for sorghum and millets and the International Development Research Centre for chickpea and pigeon pea research.

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