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PIGEONPEAS (CAJANUS CAJAN MILLISP.) : A VALUABLE CROP OF THE TROPICS.

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PREFACE

This publication contains the major aspects of pigeonpeas (Cajanus cajan) production. It has been prepared as part of a program to study Biological Nitrogen Fixation for Food Production in the Tropics and was sponsored by the Office of Agriculture of the United States Agency for International Development with the guidance of Dr. Lloyd R. Frederick.

It is also part of a series of "State of the Arts" (SOTA) publications whose purpose is to supply information relevant to legume production in the tropics and serve as a guidance for developing countries agriculture. Farmers in less developed countries need integrated packages of information on the management requirements of legumes and this publication contribues to the information that can lead to increased production in the major food grain legumes.

The College of Agricultural Sciences of the University of Puerto Rico, Mayaguez Campus, through its Department of Agronomy and Soils, makes this publication available as a technological packages that may be useful to those who are helping the small farmer in less technically advanced societies. Thanks must be given to Dr. J. Morton and Dr. Roger Smith for preparing a preliminary draft. We appreciate the efforts of Dr. M. A. Lugo López and Dr. Raul Abrams who edited the final draft of this publication.

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Pigeonpeas (*Cajanus cajan* MILLSP.): A Valuable Crop of the Tropics

(The State of the Art)

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CONTENTS

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Julia F. Morton, Roger E. Smith, M. A. Lugo-López and R. Abrams1/

INTRODUCTION

Pigeonpeas rank among the most important legume crops of the world. They are recognized to produce heavy crops of protein-rich seeds even on low-fertility soils. The pigeonpea offers a vast potential over a wide range of climatic and s[illegible] conditions in the tropics but performs best on areas where annual rainfall ranges from 500 to 1,500 mm/yr and where the soils are well-drained. It has a very deep taproot and a profusion of active, secondary roots. The pigeonpea is highly drought- and heat-resistant. Most pigeonpea cultivars are highly sensitive to day-length; flowering and seed filling occur during short days.

World production of pigeonpeas is over 2 million mt. Plantings are being increased rapidly throughout the tropics because of current widespread interest in legumes as protein sources and enrichers of the soil. The importance of the pigeonpea in the diet has been widely recognized. It is rich in high-quality protein. Dry seeds contain over 20% of good quality protein except that they are low in sulfur aminoacid and tryptophan, a deficiency common to most grain legumes.

1/Director, Morton Collections, Univ. Miami, Coral Gables, Fla., Former Associate Professor, Professor and Soil Scientist (ret.) and Professor and Plant Breeder (ret.), respectively, University of Puerto Rico, Mayaguez Campus, Mayaguez, P.R. Prepared for the Consortium on Tropical Soils, U.S. AID under contract AID/DSAN-G-0101, "Biological Nitrogen Fixation for Food Production in the Tropics."

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*Since the completion of this report, in January 1982, an excellent source of reference material has become available: "An annotated bibliography of pigeonpea" prepared by Dr. B.S. Dahiya and published in May 1980 (received at the University of Puerto Rico Agricultural Experiment Station Library on October 27, 1981) by the International Crops Research Institute for the Semiarid Tropics, ICRISAT Patancheru P.O., Andhra Pradesh, India 502-324. Dr. Dahiya's valuable contribution contains 1275 citations dating from 1900 through 1977. It was used for some of the entries included in Dr. Dahiya's publication plus additional ones, up to early 1982, obtained at the U.S.D.A. National Agricultural Library, Beltsville, Md.; at the University of Puerto Rico, Mayaguez Campus; and at several institutions visited by Dr. Lugo-López in Central America and the Caribbean.

Favorable growing conditions can lead to high yields of more than 7,800 kg/ha of green pods.

The pigeonpea is considered to be an exhausting crop that uses rather large quantities of N. Through its relatively high biological N fixation rate it can obtain enough N to supplement that which can be provided from the reserves of soil organic matter and root residues.

The purpose of this paper is to critically review the most important available literature on pigeonpeas with emphasis on the nitrogen economy of the crop. Information will be presented on the economic importance, dietary value, factors affecting production, symbiotic N fixation, transfer of N to other crops in rotations and related cropping systems and on the response of pigeonpeas to fertilizers. The ultimate goals are to provide a comprehensive source of knowledge on this increasingly important crop that will permit easy access to the literature to ascertain its potential and limitations and to provide reliable guidance for those interested in commercial or home garden production of pigeonpeas.

An updated bibliography, including 318 items dealing exclusively or in part with pigeonpeas, is included in this paper.

ECONOMIC IMPORTANCE

In India, the pigeonpea represents 10% of the total pulse crop; 29% of the crop is produced in Uttar Pradesh. The five other important pigeonpea growing provinces are Bihar, Madhya Pradesh, Maharashtra, Karnataka and Andhra Pradesh. In these provinces, it is the most important pulse crop in the kharif (monsoon) season. Since 1950, there has been a decline in production of pigeonpea and other pulses because of farmer's planting their best land to new, high-yielding strains of wheat grown under irrigation. Pigeonpea plantings have been increasingly shifted to marginal land with consequent reduction in yield even though there have been increases in the planted area. The government is seeking to step up pigeonpea production through the distribution of high-yielding, compact, short-duration cultivars suitable for intercropping (56). Export of pigeonpeas was restricted in 1972 and banned since 1973 because of high domestic prices. In India, 60% of the pigeonpea crop is marketed at a net profit to the farmer of RS 964.52 ($270.87)/ha (57).

East Africa, in recent years, has begun to promote the pigeonpea as a domestic commodity and foreign exchange earner. Malawi and Nigeria both export thousands of kilos of dried peas annually to the Bahamas. In Uganda, the pigeonpea stands fourth in importance among legumes, after beans, peanuts and cowpeas (235). In Kenya, the pigeonpea ranks 3rd or 4th among pulses and it has risen to 6th place in monetary value among food crops, the canned seeds being exported, mainly to the United States. Of the 60,000 hectares planted annually, 90% are in marginal rainfall areas (usually 500 mm /year), especially in the eastern, and drier parts of central and coast provinces, and in these areas it is the leading legume. Under drought conditions, when all other crops fail completely, the pigeonpea, even though yield is lower than in normal seasons, is the only crop which survives (5,184).

In Kenya, pigeonpeas rank 5th in value/ha to the farmer, after onions, green vegetables, potatoes and chili peppers. Production costs are lower than for the other vegetable crops (214). In the retail market, the pigeonpea is the second most expensive legume, selling at

$0.80/kg , as compared with $1.00/kg for hyacinth bean and $0.60/kg for peas and peanuts[3/].

Trinidad, back in the 1930's, annually imported from India 680 metric tons of dry split pigeonpeas (dahl), valued at $53,415. Importation was suspended during World War II, domestic production was encouraged, and the pigeonpea soon became the leading legume crop in Trinidad, the popular demand switching largely from the dried to the fresh, immature seeds. Still the supply was insufficient and, in 1961, Trinidad was importing green pigeonpeas from Tobago and St. Vincent. By 1963, there were 2,250 growers in Trinidad providing 80% of the crop and 622 in Tobago (24). In 1971, the total value of canned peas produced in Trinidad was $375,000 (309).

In Trinidad, when the first canning factory was established, the government conducted a promotion campaign and contracted to purchase the output of immature peas in the pod from all growers at 22.2 cents/kg. In 1964, the price per kg of green peas ranged from 26.4 to 35.2 cents at the peak of the season, rising as high as 79.2 cents/kg toward the end of the season. The green pea crop totaled 542,048 kg and, in addition, 4,720 kg of dried peas were marketed and 11,339 kg of dried peas were kept by farmers for home use or for seed. Today, there are three canneries and per capita consumption has quadrupled since 1963 (309). The current guaranteed price paid by the Central Marketing Agency and the processing plants is 17.6 cents per kg. Retail prices range from 22 to 50 cents/kg (36).

3/ Onim, J.F.M., Univ. Nairobi, Personal communication, 1977.

In Puerto Rico, the value of pigeonpeas has more than doubled during the past 15 years and the total crop is worth over $3 million a year. A large proportion of the canned output is exported to New York and Chicago to meet the demand of Puerto Ricans living in those cities. Nevertheless, production has decreased (a decline of 35% taking place from 1961-1971) because of higher costs, particularly of harvesting, and declining yields attributed to poor management of fields (3). To augment the local supply, Puerto Rico annually imports 500 tons of fresh, shelled pigeonpeas from the Dominican Republic (formerly also from Haití).

In Puerto Rico, fresh shelled pigeonpeas were selling for $0.81/kg wholesale from the farm, $2.76/kg on the retail market, in August 1976. There is a keen demand for large, fresh green pigeonpeas at Christmas (as in Guadeloupe). Farmers will pick them to order and charge as much as $3.30 kg in the pod; $5.50/kg shelled. However, the canning industry today absorbs 40% of the Puerto Rican crop (1,590 metric tons in 1975)4/.

The Bahama Islands, which, in 1952, exported 18,112 kg of pigeonpeas to the United States, no longer exports but imports regularly from East Africa directly or via the United Kingdom at the rate of 50,000 kg or more annually of dried pigeonpeas plus about 3,000 kg of canned peas.

The Dominican Republic and Haití have both exported to Puerto Rico--in 1974, 289 metric tons which cost $183,334 ($0.636/kg); in 1975, 500 tons. Haití has also shipped to the Bahamas, but exportation

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4/ Abrams, R., Univ. P.R. Agric. Exp. Sta., Personal communication, 1977.

of pigeonpeas from Haitî is now prohibited because it raised the retail price excessively for the consumer[5/].

Jamaica, in 1974, imported 110 metric tons dried pigeonpeas but none since, and none are exported[6/].

ORIGIN

The place of origin of the pigeonpea has been the subject of much speculation. Alphonse de Candolle considered it native to tropical Africa, from Zanzibar to Guinea. Remains discovered in tombs testify to pigeonpea culture in Egypt between 2,200 and 2,400 B.C. It is assumed to have been carried by traders to India or Ceylon. Sir Joseph Hooker, in his Flora of British India (1872-1897) reported it as cultivated up to elevations of 2,000 m in the Himalayas.

It was well established in China and Indochina and some islands on the East Indies at an early date, though it was slow in reaching the Pacific Islands. In 1772, it was introduced into Guam via the French ship "Castaries." Late in the 18th century it was planted in Hawaii. Brown (50) wrote in 1935: "Of very recent introduction in the Marquesas where it is cultivated in a few places on Nukuhiva and Hivaoa". Oza (192) believed that India was the original home of the pigeonpea before it spread to the new world.

Seeds are believed to have traveled the slave route from Africa to Bermuda, the West Indies, the Guianas and Brazil. In time, the plant

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5/ Synne, V.A., Haitî Seed Store, Kenscoff, Haitî, Personal communication, Oct. 10, 1977.

6/ Martin, E.R.H., Ministry of Agric., Kingston, Jamaica, Personal communication, 1977.

became widely distributed and more or less naturalized throughout the tropics, in some areas being an indispensable food source, in others valued mainly as a forage or cover crop, or remaining an occasional or minor, dooryard resource. In Mexico, the pigeonpea is little known outside of Yucatán. It was probably first brought to Florida by fishermen and spongers from the Bahamas who settled on the Florida Keys and in Coconut Grove and grew the bush in their dooryards.

BOTANY

The genus Cajanus belongs to the order of Leguminosae, suborder Papilionaceae. It embraces a single species, Cajanus cajan (L.) Millsp., commonly referred to as pigeonpea (177). The pigeonpea is an erect, perennial or annual, bushy shrub to 6 m high, woody at the base, with somewhat ribbed, downy stems and has a vertical taproot (penetrating to 1 m or more) and numerous rootlets, some bearing nodules inhabited by nitrogen-fixing bacteria (Rhizobium). The leaves are pinnately 3-foliolate, with lanceolate or elliptic leaflets 4 to 10 cm long and to 3 cm wide, acute at the apex, dark-green and silky on the upper surface, densely silvery-downy and dotted with glands on the underside. Flowers, borne in short axillary and terminal racemes, are 1.5 to 1.8 cm long, yellow to orange-yellow, the standard often striped or splotched with dark-red or purple, or entirely red or purple, on the outside. The pedicles and Calyx are brown-velvety. Seedpod is indehiscent, green, maroon or dark-purple, or green blotched with maroon or purple; oblong, to 8 cm in length and to 1.4 cm wide, more or less downy, obliquely constricted between the seeds, and terminates in a slender beak. The fresh hull contains an aromatic, slightly acrid juice. Seeds, 2 to 9 in number, are nearly round, smooth, 4 to 8 mm. in diameter, green when immature; when mature, are white, gray or yellow, sometimes mottled with purple-red; or are light - or dark-brown, entirely red or black or black speckled with white. They are very hard when mature and dry, become soft and enlarged when soaked. Weight of 100 seeds (dry) varies from 4.5 g to 16.4 g. Number of seeds/kg ranges from 1,150 to 3,630. The pigeonpea plants exhibits great variation in size, habit, seed characters and photoperiodic behavior.

Most types flower when days are 11 to 11 1/2 hours in length (128). Certain cultivars have flowered earlier under a 10-hour daylength than under daylengths of 12-14 hours (13). Some are insensitive to daylength and will flower at any time of the year. Usually, flowering begins in 120-150 days and seed maturity in 250 days from planting date, but flowering may occur as early as 60 days and seed maturity in 100 days in early types (266).

Genotypes and cultivars may be placed roughly in two main divisions--C. cajan var. bicolor DC. (called arhar in India) includes primarily large, long-lived, late-maturing plants bearing red-or purple-stained flowers and hairy, purplish pods with 4 to 5 seeds usually purple-mottled or dark-colored. C. cajan var. flavus DC. (called tur in India) includes mostly smaller, early-maturing plants, with all-yellow flowers and light-green pods having only 2 or 3 seeds. There are intermediate forms and crosses which display characters of both and do not fit into either division.

UTILIZATION

The dietary importance of the pigeonpea has been widely recognized. It is rich in high-quality protein (averaging 7%, in unripe seeds; varying from 18 to 32% in mature seeds) and, while deficient in methionine, cystine and tryptophane, is an excellent food when eaten with rice (80% rice, 20% pigeonpeas).

The chief proteins of the pigeonpea are two globulins: cajanin, which represents 58% of the total N and concajanin, which represents 8% (130,160,286). Cajanin contains most of the methionine, cystine and tyrosine but is low in tryptophane, threonine and lysine (286). Vitamin content varies widely with the strain of pigeonpea.

Fatty acids are: linolenic, 5.56%; linoleic, 51.41%; oleic, 6.33%; saturated fatty acids, 37.7% (130). Pigeonpeas are low in antimetabolites and flatus-inducing sugars, and the testa is free of lipoxidase which can cause off-flavors in soybeans and other legumes (213).

The raw seeds contain the enzyme urease, a single form of a-galactosidase, and the newly discovered enzyme B-L-arabinosidase (79). Phytin-phosphorus (75-89% phytin) is present at the rate of 200 mg per 100 g of seed (130).

In India, the Malagasy Republic, the Bahamas, Puerto Rico, Trinidad and Tobago, the Windward Netherlands Antilles, Panama and Guyana, the pigeonpea is almost an indispensable food. In most of Central America, it is not popular with the Indians or persons of Spanish descent, but favored by residents of West Indian origin.

In India, the pigeonpea is the second most important food legume, but pulse consumption has been declining in favor of cereals. From

1959 to 1971, the per capita availability of pulses in India fell from 75 to 50 grams/day and a decline to 36/day is anticipated by 1980. Nutritionally, this change in the pulse/cereal ratio is undesirable and the government is seeking to correct this trend. Experimental diets of 7% cereal protein and 3% pulse protein have been shown to be superior to diets containing either 10% cereal or 10% pulse protein.

It is consumed mostly as dried seed. The dried peas are always split in order to remove the leathery seedcoat, and this serves to speed cooking time. It has little effect on food value since the seedcoat is high in fiber, low in nutrients, and has relatively low digestibility. Splitting and hulling is done in hand mills operated by the growers or in hand- or power-mills used by dealers. Generally, the hulled seeds, called "dhal" (a term applied also to other dried, split legumes), are made into a puree eaten as a side dish with curries (143). In the days of sailing ships, the dried peas were reduced to a meal or so-called "sago" which was in great demand for sea-fare.

Mature, dried, whole, unsoaked seeds need to be cooked 4 to 5 hours. Williamson (310) believes the mature pigeonpea would be more acceptable to people in Malawi if the slightly acrid and tough seedcoat were always removed. He says this can be done by parboiling and then pounding with wood ashes, or by boiling with ashes; or by pouring on boiling water, steeping for 5 minutes and then skinning the seeds by hand; or by grinding the seeds and winnowing off the seedcoats (310). The Acholi tribe of Northern Uganda has a daily per capita consumption of 36 g dry pigeonpeas in midsummer. The pigeonpea is little appreciated as a food by West Africans except in the former French colonies of Dahomey and Lower Congo. There are marked tribal attitudes toward this legume.

In Java, mature, dry seeds are soaked in water, pounded and fried, or are steamed and eaten alone or mixed with grated coconut or other foods. In the West Indies, generally, the dried seeds are boiled thoroughly and eaten with rice or used in soup. In the north of England, the imported dried seeds are soaked overnight and cooked as soup[7/].

Food technologists in India have found that cooking time and fuel consumption can be reduced by mechanically flaking the decuticled, dried pigeonpeas, then steaming the flakes for 15 minutes to reduce the viscosity of the pot liquor. When the peas, thus prepared, are put into boiling water to cook, they become tender in 10 to 20 minutes (78). Ripe seeds may be germinated as are mungbeans to produce sprouts which are eaten when 2 cm in length. Immature seeds have a much wider appeal than mature, dried seeds, because they are tastier, tenderer, do not need soaking, and cook in less time. However, they are more difficult to shell. Depodding is done by inserting the thumbnail near the apex and drawing the thumb down toward the base, to split the pod and detach the seeds.

In Java, the young seeds are mashed with onion and other flavorings and eaten raw with rice. Elsewhere, they are usually boiled, thorough cooking requiring 1-1/4 to 2 hours. On the Island of Curacao, they are often pretenderized by first frying in a little oil, then they are boiled till soft, the water is poured off, and the peas are fried with bacon and onion.

7/ Tropical Products Institute, England, Personal communication, 1977.

In Puerto Rico, the fresh immature seeds are very popular and sell for at least twice the price of the mature, dried seeds. There, and in the Bahamas, they are traditionally cooked with onions, green peppers, garlic, tomatoes and rice, and, in the Bahamas, the "peas and rice" is a dish eaten daily by the majority of the population.

Pigeonpeas are canned commercially in Puerto Rico since 1928 and in Trinidad and Tobago since 1962. In canning factories, the immature, pea-filled pods are steam-scaled for 90 seconds to inactivate the peroxidases, then the peas are mechanically shelled, processed and canned in water and salt. Mature, dried peas are canned after presoaking.

Pigeonpeas are successfully quick-frozen when midway between the tender and overripe stages. As in canning, enzyme inactivation is necessary to avoid undesirable changes in flavor, texture and appearance.

The growing plant is readily grazed by livestock. Lopped branches are fed fresh or dried to cattle and horses, as are the pod husks, leaves and broken seeds after threshing operations. Puerto Ricans have fed the empty pods, moistened with slightly salted water, to their oxen. It has been calculated that the pod husk (or shell) represents 60% of the price paid by weight to the farmer for peas in the pod.

In India, the seedcoats removed in the splitting of the peas and which represent 10% of the raw material, are prized as feed for dairy cows, as are also the "dust" and broken seed fragments, but these sell at a higher price. Such byproducts are incorporated into several commercial cattlefeed mixtures (143).

In Hawaii, the pigeonpea has been grown mainly as feed for domestic animals--the plant for horses, mules, cattle, swine and goats, as hay or milled to a meal; the seeds, flowers and buds for ducks, chickens, turkeys, pigeons and rabbits (142). In the north of England, where there are many pigeon fanciers, the dried seeds are imported (up to 100 tons annually) mainly as pigeon feed.[7/] Chicken feeding experiments in Australia showed that pigeonpea seed meal fed to chickens from hatching to 6 weeks, at the rate of 5-30% of total rations, produced body weights equal or superior to those of control birds on maize and soybean meal. When the rate of pigeonpea meal was raised to 40%, body weights were lower than those of controls, possibly due to aminc acid deficiencies (305).

Around 1920, the protein value of the plant was discovered in Hawaii to be about equal to that of alfalfa which, of course, is rarely grown with success in the tropics. Cows fed podded green tops produced more milk than when on an alfalfa diet. It was established that a pasture of 3-year-old pigeonpeas could maintain 2.47 to 3.7 head of cattle/ha all year, producing 147 to 183 kg body weight/ha/annum. Within a decade of this discovery, there were about 10,000 acres (4,047 ha) planted to pigeonpeas in the Hawaiian Islands and it was declared that "no other leguminous crop is known to have yielded so consistently year after year as has the pigeonpea" (142).

The approximate composition of the upper third of pigeonpea stands cut as hay has been reported as: 70.00% moisture, 7.11 to 11.8% crude protein, 1.65% fat, 7.88 N-free extract, 10.72% crude fiber, 2.64% ash, 0.25% phosphoric acid, 0.90% potash and 0.42% lime. The plant's protein content is higher in the early stages of flowering than in the advanced podding state.

The digestibility coefficient for the crude protein of pigeonpea hay dried at 100° C is 71.5 to 88% (14).

In Queensland, grazing trials comparing five pigeonpea accessions, unfertilized, with *Setaria anceps* cv Kazangula, were conducted for two cool seasons. Pigeonpea produced 1 kg /ha /day early in the grazing period but the plants were greatly reduced in the second season, partly because of a heavy infestation of the scale, *Coccus langulus* Douglas. Accordingly, liveweight was maintained longer in both years by *S. anceps* (305).

In Florida, Stambaugh produced 55 to 80 metric tons of fodder/ha on cleared pineland and two crops/year, but a roused little interest among cattle ranchers (279). Pigeonpeas have been grown as a windbreak to protect tobacco; as a cover crop in coconut or tea plantations; as a shade for coffee, tea or cacao; and as support for vanilla. The plant has great value as green manure but, being rather woody when old, is somewhat difficult to plow in. If grown for green manure or for fodder, it may be pruned regularly over a period of 3 or 4 years. In Hawaii, solid plantings of pigeonpeas have been maintained 4 to 5 years and then plowed under to prepare the ground for pineapple growing.

In Northern Australia, the pigeonpea is sometimes grown as a green manure rotated with pineapples or bananas; in the Malagasy Republic, it is alternated with rice. In the porous oolitic limestone of the Bahamas, the pigeonpea is often rotated annually with tomatoes so that the leaf fall will enrich the pockets of organic material in which the tomatoes are raised. Leaf fall can amount to 2,200 kg /ha dry matter containing 36 kg nitrogen (71).

as a nitrogen-restoring crop for fallow land between maize plantings, the pigeonpea has a more favorable effect on the subsequent yield of unfertilized maize than does grass or regenerated bush. However, trials in Southern Rhodesia have shown that maize yield is greater after velvet beans than after pigeonpea; and, in India, cotton gives higher yields of seed after rotation with peanut (groundnut) than with pigeonpea (103).

When grown as a windbreak, the pigeonpeas should be planted 3 m from the nearest crop row to avoid root competition and the flowers are plucked periodically in order to induce dense leafy growth. In Australia, it is being used to revegetate bauxite-mined areas on red lateritic soils.

Indian breeders in 1953 reported a spontaneous mutant from the F_3 generation of a hybrid with erect parents. The mutant was prostrate and viewed as potentially useful as a ground cover (10).

In the Malagasy Republic, the pigeonpea has been grown for rearing a special silkworm, Boroceras cajani, which feeds on the leaves and forms its cocoons among tufts of grass placed within the bushes for that purpose. The plant was grown in northern Bengal and Assam as a host for the lac insect at the beginning of the 19th century and it is cultivated for this purpose in parts of India and Thailand at the present time. If pruned to prevent flowering, the plants can be maintained as lac hosts for several years.

The dried stems of the bushes produce fire by friction and have served as matches. They are used for fuel in India and those of the largest size burned for charcoal which is utilized in making gunpowder. In Hawaii, the charcoal was found good for poultry, "comparing favorably in this respect with willow charcoal." Thin, straight branches have been made into baskets, thatching for roofs, wicker lining for wells and wattling of carts. Wherever other materials are available for these purposes, it would be wiser to chop the pigeonpea stems and incorporate them into the soil for field enrichment. Today, mechanical choppers of various capacities are available.

Wherever the pigeonpea is grown, various parts of the plant as well as the pods and seeds have sundry uses in folk medicine. Potential therapeutic value is indicated in the report of biochemists at the University of Kerala. A protein fraction from dried, powdered pigeonpeas, administered to rats on a high cholesterol diet, lowered the total and free cholesterol, phospholipids and triglycerides levels in the serum, liver and aorta (206).

There have been conflicting reports on the pigeonpea as bee forage. Krauss (142) wrote in 1932 in Hawaii: "Bees frequent the profusely flowering plants in great numbers whenever the weather is favorable." He assumed they were gathering nectar, for he added: "The pigeonpea flower is a source of honey." However, Ordetx Ros, who made an extensive study of bee plants in Latin America, reported that the flowers contain little nectar and are visited by few honeybees (191). Sardar Singh, ([illegible]) in evaluating the pigeonpea and other garden legumes as bee pasturage, states: "These pulses are grown all over India in fairly large areas, but bees visit them occasionally to collect pollen. These plants cannot be depended upon."

CULTIVAR SELECTION

India: The Imperial Economic Botanist in Pusa, India, surveyed the types of pigeonpea in that country in 1928-29 and collected 107 distinct strains. In 1933, 86 types were collected throughout India.

The following genotypes and cultivars have been reported, from India, as having certain characters of interest: RG-37, RG-72 (A.P.), SA-1 (T.N.), Vijapur 49, T-15-15 (Gujarat), Thogari-2 (Mysore), B-7 (West Bengal), N-84 and N-148 (Maharashtra), ST-1 and PM-1 (A.P.). They are among those which were developed either through single plant selections from local populations or through hybridization programs.

NP(WR)15, C-11, F-18 and F-52 were the result of efforts to breed for wilt resistance and all show 80% resistance to the disease in various regions of the country.

S-3 and R-60 are resistant to stem rot and wilt diseases, respectively, and are being used in breeding (128). Chaffa, C-235, G-130, H-208, BGS-1, BGS-2 and G-62-404, have exhibited wilt and blight resistance and give high yields.

Type 1, reported in 1961, is a pigeonpea of spreading habit, maturing its crop in 145 to 150 days, with a high yield of large seeds. Type 7 has been recommended for high yield of seed. Type 17 is not remarkable for high yield but for wilt resistance and good cooking quality. Type 21, maturing seeds in 132-150 days, surpassed Type 1 in number of seeds/pod (4.1), as well as in cooking quality and flavor. Mean 100-seed weight is 7.71 g. Type 105, is wilt-resistant, of good cooking quality and a better yielder than Type 17. ST1, ST2, and ST3, earlier selections, showed high resistance to wilt and exceptionally high yields. No. 1141 was noted for its short-season crop and good yield under irrigation (14).

Upas 120, a mutant recognized in Uttar Pradesh in 1969, was tested and found to mature in 100 to 142 days, with a mean of 120, and has good agronomic qualities. Yield is equal to that of T-21 and Pusa Ageti (264). Average number of seeds/pod is 4.1; 100-seed weight, 6.24 g.

Other early-maturing, improved varieties are Prabhat (120 days to maturity; 3.6 seeds/pod; 100 seed weight, 6.36 g); Pant A-2 (maturing in 141 days; 3.7 seeds/pod; 100-seed weight, 6 g); Pant A-3 (maturing in 137 days; 3.6 seeds/pod; 100-seed weight 9.30 g; fairly resistant to wilt (29).

Five varieties--BR13, BR59, BR60, BR65 and BR71--were evaluated at the Ranchi Agricultural College, Kanke, India. Seeds were planted on July 20, 1968 and June 10, 1969. Days to flowering ranged from 71 to 78 days the first year; from 101 to 132 days the second year. The flowering period extended 61-69 days in 1968 and 68-95 in 1969. Pods gained full size in 18-22 days and matured in 44-54 days after pollination. BR183, Khargaon-2, RG-72, Sharda and Makta are medium-duration varieties planted in early June before the monsoons (253).

Seven strains of pigeonpea, T-21, Hy-1, H -2, Hy-3A, Hy-3B, Hy-3C (ICP-7199), and Hy-4 were studied at the Indian Agricultural Research Institute (IARI), Regional Research Station, Rajendranagar, Hyderabad. Hy-3A, Hy-3B and Hy-3C are sister lines of economic worth isolated from a single accession, #2817. Hy-3A and Hy-3B differ only in seed color. Hy-3C has orange-red flowers and more basal branching; Hy-3A and Hy-3B have yellow flowers and are lacking in basal branching.

Pusa Ageti, a relatively short-duration strain (150-160 days to maturity) with a mean 100-seed weight of 8.91 g, together with T-21, ST1, ICP-1 and Hy-3C, were utilized in normal and off-season planting trials at the International Crops Research Institute for the Semi-arid

Tropics (ICRISAT), Hyderabad, in 1974. The yield of Pusa Ageti was 1,069 kg /ha ; of T-21, 1,186 kg /ha dry seed.

Gwalior-3 (tall, spreading) and NP-69 (medium height, compact) were crossed at the Regional Agricultural Research Institute, Gwalior, and, in 1970, 600 plants of the F_2 generation of this cross were planted for studies of high yield factors (219).

Five genotypes were tested at Coimbatore in the summer of 1973. S41 showed the highest pod set, followed by S31, S19, CO-1 (#1141) and CO-2. Highest seed yield was achieved by CO-1, followed by S19, S31, S42 and S41 (221).

CO-1, an annual type maturing in 4-1/2 months, extensively cultivated in Tamil Nadu, has copper-colored seeds. SA1, also an annual much cultivated in Tamil Nadu, matures in 6-1/2 months, has mace-colored seeds. These two annuals have beencompared with three popular perennials--MS9537, PLS363, and PLS364 having flesh-colored seeds. The annuals have smaller seeds, are richer in protein (20.9-21.4 vs. 18.0-18.3%) and cook in less time (25.1-26.4 vs. 33.4-38.0 minutes) (223). SA1 proved more satisfactory in cooking than 9 introduced cultivars compared with it in tests in Madras (14).

At Punjab University, 220 lines of pigeonpea have been analyzed for protein content--H18 (yellow-brown seeds) and C4784 (brown seeds) are high in protein, 23.6 and 24.5%, respectively. H13 (dark-brown seeds) and H384 (white seeds) are low in protein, 18.3 and 17.5%, respectively.

Screening of 2,084 accessions (strains of pigeonpea, Atylosia spp., and Atylosia X Cajanus hybrids) revealed ICP-3783, -6986, -6997, -7035 and Hy-3C to be immune to sterility mosaic disease (182).

In general, the large-seeded, light-colored strains of the Central region are popularly regarded as having the finest quality and "aroma" and sell for the highest prices in India.

Malaysia: In 1975, 21 cultivars were evaluated at the RRIM Experiment Station, Sungei Buloh. The tallest, SS9, reached a height of 227 cm. Cultivar 6A7 grew tall and bushy. A dwarf variety, SS4, attained only 75 cm (25).

Australia: In 1969, 95 lines--10 Australian, 63 Indian, and 22 from 9 other countries--were classified according to 31 attributes. They were ultimately sorted into 15 groups. Especially noteworthy among the lines individually evaluated was UQ50 which gave the highest yield (7,600 kg oven-dried seeds/ha). It is tender-seeded and, because of its large pods is considered the best for manual picking. UQ34, UQ67, and UQ68, were rated as desirable, with a high yield of tender seeds but relatively small pods. Hard-seeded, high-yielding types included UQ12 and UQ19. UQ56, also hard-seeded, had the largest seeds but a low yield. UQ59 was the only type attacked by "littleleaf" disease (10).

Between September 1970 and March 1972, at the University Farm, Redland Bay, a coastal subtropical area of southeastern Queensland, four genotypes were set out in test plantings. UQ1 and UQ38, both short-day, late-maturing lines, sown during early and mid-season, exhibited intensive pod ripening and maximum seed yield/harvest.

UQ39, less photoperiodic, nearly day-neutral, and UQ37, intermediate in sensitivity, both early-maturing, were characterized by prolonged growth period, a succession of flowers and pods extending the harvest season, and were judged unsuitable for mechanized dry seed production (11).

In 1973-74, five selections were chosen for evaluation in south-eastern Queensland--UQ11, early maturing; UQ18, early maturing, UQ34, late maturing; UQ50 (from the West Indies), short-day, midseason; UQ68, late-maturing. Results were disappointing because of unfavorable weather conditions and trials of these types were repeated in 1974-75 (305). UQ50 bears pods in the upper 30 cm of the canopy and is, therefore, well suited for mechanized harvesting, but has the disadvantage of a long growing season (110 days to flowering), maturing in winter when yield is lowered by drought. Interest is now centering on a 1976 accession, ICP-7179, which flowers in 60 to 65 days.

Uganda: In 1968, workers at the Makerere University Farm made test plantings of seeds collected in various parts of the country. In 1969, the World Collection of Cajanus (consisting of 5,000 strains) was acquired from India and subsequently 538 strains were added from other parts of East Africa, South America and Puerto Rico. Breeding and agronomic studies include crossing, evaluation and testing of 718 elite lines. Some promising lines mature in 125-139 days and can be double-cropped. Their yield potential ranges from 889 to 1,228 kg /ha dry seed. Among those tested ·e l (Civei), of Uganda, UC984, UC2288, UC3035, of India, and UC16, from the Philippines, with secondary branches nearly as long as the main stem and few tertiary branches--classed as "spray types"--and UC959 and UC1377, from India, classed as "bush types." The dwarf UC11, used in outcrossing trials, flowers very early and exhibited up to 8% cross pollination (134).

Nigeria: The International Institute of Tropical Agriculture (IITA), has selected cultivars from elite stocks identified or developed in their breeding program. The following, derived from advanced lines and segregating stocks of recombinations from different parental sources, are adapted to a wide range of climatic conditions, have deep taproots and are resistant to drought and heat; fairly insensitive to daylength between latitudes 10° North and 10° South; flowering in 65 to 90 days after planting: 3D-8104; 3D-8111; 3D-8125; 3D-8126; 3D-8127; 3D-8129. These lines have been widely distributed in both hemispheres for trial by cooperators (27).

Trinidad and Tobago: In 1937, dwarf, small-seeded, early-fruiting types were introduced into Trinidad and Tobago from Pusa, India, especially for making dhal (split, hulled seeds). Local selections made in Trinidad were named St. Augustine, Tobago and Lasiba. The last two, still popular with small farmers, are tall, indeterminate, daylength sensitive, late-maturing, large-seeded cultivars. Lasiba has a thick-walled pod with resistance to pod borers, and generally produces 7 to 9 seeds/pod.

Tobago seeds are soft-coated and "sweet" in the green stage. CG12/3, G125/2, G154/3, are the most planted of late releases. They are semi-dwarf, determinate, daylength sensitive; have relatively short cropping season; are suitable for planting in December as row crops (36)

G154/3, in test plots, has yielded 8,970 to 14,570 kg /ha green pods. 03/59 Grenada Large-podded, with 6-7 seeds/pod, has yielded 8,970 kg /ha. Now recommended as "ideal varieties" are two dwarf types--U.W.I. Code 1 and Chaguaramas Pearl. The latter is a selection from U.W.I.

Code 1 made jointly by the Ministry of Agriculture and the German Government Project at Chaguaramas (37).

Trinidad Dwarf #5 was supplied by the University of the West Indies for Rhizobium trials at the Rothamsted Experiment Station in England (69).

Puerto Rico: In Puerto Rico, Amarillo, a short, indeterminate cultivar, planted in spring, produces its crop from November to April. Kaki (Caqui), the most popular cultivar bears more heavily but for mainly 3 months beginning the middle of December. Often a second crop is borne, beginning in mid-February (32). The plant averages 264 cm in height; requires 140 days to flower. The pod varies from brown to kaki in color; the seeds are large and clear green. Yield in 1962, at a spacing of 0.61 x 2.44 m , was 8,190 kg /ha green pods. Kaki has performed best in Sao Paulo, Brazil, when planted in January and harvested in July (155).

Saragateado has a mottled pod, large, clear green seeds and a usual yield of 3,350 kg /ha. Totiempo, extremely indeterminate, planted in January, bears a light crop in mid-year and another in November[4/].

Florido is a long-podded type having 7 to 8 seeds per pod but the seeds are small and the hectare yield by weight is low.

Vaininegro, an indeterminate type with purple flowers and dark-brown pods, is grown only in home gardens[4/].

2B-Bushy is an early maturing (requires 75-84 days to flower), semi dwarf type which appears to be daylength insensitive.

Among unnamed indeterminate types being tested in Puerto Rico are:

Line 7, which is 264 cm tall; requires 134 days to flower.

Line 12, 273 cm tall; requires 134 days to flower.

Line 142A, 282 cm tall; requires 153 days to flower.

Line 69-KT-1, 270 cm tall; requires 135 days to flower.

Line 69-KT-2, 261 cm tall; requires 140 days to flower.

Line 69-KT-6, 264 cm tall; requires 139 days to flower.

Line 69-52 294 cm tall; requires 155 days to flower.

Line 69-68, 246 cm tall; requires 139 days to flower.

Line 69-58-1, 276 cm tall; requires 139 days to flower.

Line 69-58-2, 270 cm tall; requires 159 days to flower.

Line 82-A, 300 cm tall; requires 139 days to flower.

Among determinate, semi-dwarf types being tested are:

16A, which requires 77-89 days to flower.

21-B, which requires 83-92 days to flower.

Two other unnamed lines are: 8AB and 8AB-7 (2).

Guadeloupe: Evaluation of 200 accessions has focused attention on the following cultivars as having characteristics that hold promise for pigeon pea advancement under local conditions:

Goyave-2 (early and determinate); Kaki; Marie-Galante; Grands-Fonds-4--all relatively tall, erect, with short-cropping period, however, Grands-Fords-4 is handicapped by small pods and seeds.

GI 54/3 is a dwarf type, determinate, and early maturing.

56.57.2A (indeterminate), GC 12/2, and Bagatelle are daylength insensitive and all three, especially Bagatelle, are of especial interest because they do well on humid volcanic, acid ferrasols, as well as on dry limestone soils. Unfortunately, Bagatelle has small pods and small seeds.

Mounien is a semi-dwarf, more or less determinate in habit and having satisfactory characters except for small size of pods and seeds.

La Sieva is semi-dwarf, indeterminate, late-maturing; produces high yields under favorable conditions but is intolerant to acid ferrasols.

Rejects include Juliette and Crosse-Montagne because they are too indeterminate and not suitable for efficient methods of harvesting.

Vernou was rejected because of small seed size; and Retraite-2 because of very flat pods and high susceptibility to insect attack (76).

Jamaica: Jamaican farmers grow indeterminate types which produce pods over a fairly long season, thus suiting the needs of the home consumer and the local markets.6/

Venezuela: Panameño, a cultivar selected and released in 1972 by the Facultad de Agronomía de la Universidad Central de Venezuela, is of relatively short height, fairly uniform maturity of crop, short producing season and of good shipping quality. Tests have shown it suitable for canning (230).

North Carolina and Florida: A strain from Pakistan (P.I.219066) was tried out at the University of North Carolina in 1966 and 1967 (as green manure and source of chickfeed), given the name Norman, and some seed sent to the University of Florida. The Norman strain, because of its satisfactory performance, was briefly publicized in 1968 as "a new agronomic crop for Florida". In comparison with 39 other accessions evaluated at Gainesville, Norman gave the highest seed yield. Seed count averages 2,637/kg (139). At present, the University of Florida is making selections from 100 accessions from India. Dr. Fike, of

North Carolina State University at Raleigh, has acquired a new stock of Norman seed from a planting which he arranged to be made in Africa.

Hawaii: A breeding program was started at the University of Hawaii in 1919-20. Over 100 named cultivars were introduced from India, The Philippines, Puerto Rico and Florida, and, by 1932, 500 hybrids were under trial. A chance hybrid, New Era Strain D, small-seeded and prolific, was viewed as holding the greatest promise and 200 types of this strain were being tested. New Era was inbred for 20 generations, then distributed to growers and soon was extensively cultivated. Considerable effort was devoted to the introduction and trial of early-maturing types from northern India which might succeed in fertile upland ranchlands where a pasture legume was needed. New Era Strain .., strongly erect, with deep taproot, was crossed with a small-seeded Indian variety, resulting in Strain Z with many seeds/pod and half as many pods as leaves (14). In 1929, interest shifted to another forage legume, koa haole (lead tree, ipil-ipil), and today the pigeonpea is seldom planted in Hawaii except by people who raise goats.

GERMPLASM INVENTORY

The Food and Agriculture Organization (FAO) of the United Nations is preparing a basic program for storing and retrieving pigeonpea germplasm data, using the TAXIR system. First, accessions must be adequately described, duplicates eliminated and a feasible classification system developed.

The International Crops Research Institute for the Semiarid Tropics, Hyderabad, India, has listed 28 qualitative and quantitative characters for evaluation of accessions to determine yield potentials:

1. Days to flower
2. Maturity group
3. Flower color
4. Plant height
5. Plant width
6. Growth habit
7. Number of primary branches
8. Number of secondary branches
9. Number of pods/plant
10. Pod size
11. Pod color
12. Number of seeds/pod
13. 100-seed weight
14. Seed color
15. Testa structure
16. Seed form
17. Cotyledon color
18. Seed yield/plant
19. Straw yield/plant
20. Reaction to major pests and diseases (flower duration, escape and resistance)
21. Protein content and amino acid pattern.
22. Other biochemical relationships.
23. Tolerance to drought, water-logging and alkalinity
24. Response to high fertility and irrigation
25. Plant Architecture and leaf angle, leaf size and number
26. Seedling vigor
27. Nodulation capacity
28. Male sterility

Other quality considerations must include nutritional value, digestibility of protein, and cooking quality, factors which may differ greatly with variety.

INDUCED MUTATIONS

Seeds of cultivar CO-1 have been subjected to 0-26 K rad gamma radiation and 0-80 m*M* EMS (ethyl methanesulphonate). Gamma radiation produced more viable mutations, more early-maturing and high-yielding mutants. Both treatments resulted in dwarfing of plant, reduction in branching, number of pods per plant and pollen fertility (128).

At Jabalpur, India, diploid and colchicine-induced tetraploid seeds were exposed to various levels of gamma irradiation--0, 14, 20, 30, 40 and 60 K rad in a ^{60}CO source. In diploids, germination survival, seedling height and number of leaves were reduced with increased irradiation doses. In tetraploids, the initial dose of 15 K rad increased germination, seedling height and number of leaves, but higher doses caused decreases (262).

In Puerto Rico, cultivar Kaki was subjected to irradiation with gamma rays and neutrons. The X_2 generation showed much variability in plant height and period of maturity (14). Sixteen of the radiation-produced lines (143, 163, 166, 344, 346, 425, 426, 432, 456, 462, 526, 536, 611, 616, 643 and 664) were compared over a three-year period with four established cultivars in plantings at two locations. Mutation #346 gave the highest yield at both sites. Performance of all others varied considerably (5).

The early-maturing 2B-Bushy, a short type, has been treated with gamma rays in a program intended to develop truly dwarf types (less than 60 cm tall) which are daylength insensitive (2).

FACTORS AFFECTING PRODUCTION OF PIGEONPEAS

Climatic Factors

The range for growth of the pigeonpea lies between latitudes 30° N and 30° S, at low elevations. It is sensitive to frost, requiring a temperature regime of 20° to 40° C during its life cycle. In Central Florida, plants have been undamaged by brief periods of -2.2° C, have been defoliated by -3.3° C, and killed to the ground by -4.4° C (280). Ten hours of temperatures between -2.7° C and -1.1° C killed plants outright in January 1977.

Pigeonpeas are cultivated in both moist and dry subtropical and tropical regions, the former favoring vegetative growth, the latter higher seed production. The plant thrives in regions with annual rainfall as low as 500-630 mm. In India, pigeonpea culture is successful over a precipitation range of 500 to 1,500 mm/year (258).

In Venezuela, this crop is grown from sea level up to an elevation of 3,000 m ; in Java, 2,000 m ; in Jamaica, up to 1,100 m. Best growth is achieved in Hawaii between 30 and 457 m. Plants tested at elevations between 1,067 and 1,524 m failed to set fruit in Hawaii (142).

Soils

The pigeonpea is noted for greater soil adaptability than other legumes. The plant prefers well-drained, deep, sandy loam. However, it does well in shallow, inferior, marginal soil and in a wide range of soil types in India ranging from light, shallow red soils to heavy, black clay soils, but more nodules form and remain active and the plant takes up more N in the lighter red soils than in the black soil. In Queensland, cultivar CPI-18301 gave far higher seed yield on Cununurra clay than on dryland Cockatoo sand (14).

The plant can endure soil salinity of 0.0005 g NaCl/g but not more than 0.0010 g (142).

pH: The pigeonpea seems well adapted to a soil pH as low as 5 and as high as 8 (258). It appears to thrive best in neutral or alkaline soil but produces fairly well in slightly acid conditions (145).

Mo levels: Mo is essential to N fixation. In Mo-deficient soils, many small nodules develop but are relatively ineffective; when Mo is added, nodules are fewer, larger and more efficient. In pot culture, Indian investigators observed the beneficial effect of Mo at 1.25 and 2.5 p/m on elongation of pigeonpea roots and shoots, dry matter accumulation and free amino acid levels. The highest Mo treatments maximized accumulations of arginine, glycine, serine, asparagine, histidine, and lysine, but decreased B-alanine in the shoots by the 41st day after germination (213).

Other nutrients: P is a critical factor in pigeonpea nutrition. In the Eastern Province of Kenya, in a trial of a locally developed composite cultivar, on sandy loam, seed yield increased in proportion to P application (0 kg , 45 kg , and 90 kg /ha) (184).

In fertilizer experiments at New Delhi with cultivar T-21 under rainfed conditions in a sandy loam of low fertility, grain and dry matter yields increased progressively with applicationsof 33, 67 and 100 kg P_2O_5/ha , and were comparable with applications of manure at levels of 15, 30 and 45 tons/ha. With all costs of production taken into consideration, the potential net profit to the farmer also rose in proportion to the rate of P_2O_5 applied. Smaller profit increases would be realized from manured crops because manure is more costly in India (57).

Yields in cultivar SA1 have been increased by 13.5% by applying 22.4 kg P_2O_5 tons of compost/ha on red soil low in N, P and K (296).

Soil deficiencies in N, P and Fe have little effect on nodulation and fixation of N, but deficiencies in P, Ca and Mg have depressed nodulation and plant growth significantly (213).

In a two-year, sandy-loam field experiment at the Indian Agricultural Research Institute (IARI), application of P at rates of 50-100 kg /ha increased the crude protein content of pigeonpea seeds, especially those harvested from the inoculated strains AS-3 and T-21. Strains AS-5 and P04785 showed lesser gains. Highest P treatments were beneficial in increasing protein content and N uptake only in the first year (270,295).

S has been found essential to the nodulation of legumes. In pot culture, S at 100 p/m in combination with low levels of N, P, K has significantly increased the methionine content and dry weight of pigeonpea plants and the number and dry weight of root nodules. Without S, applications of N, P and K had no effect on methionine content. Methionine content was not further improved by raising S application to 200 p/m (188).

Zn deficiency is common in pigeonpeas in India and can be corrected by soil application of 2 to 4 p/m Zn or foliar spray of 0.5% zinc sulfate with 0.25% lime (253).

Cu is essential to N fixation. In studies with other legumes, it has been found that when this element is lacking or seriously deficient, there will be less N fixed in the presence of effective strains of *Rhizobium*. It is also known that a suitable increase in Cu level will offset the inhibitory effect of more than the recommended minimum of applied N on the N-fixing activity of rhizobia.

Plant Factors

Not only are most cultivars of pigeonpea extremely photoperiodic, but the plant is also highly sensitive to variations in light throughout the day. Leaves on the outer branches of the plant constantly change position in relation to the sun: at sunrise their upper surfaces are at right angles to the rays of the sun; later in the day, parallel; in the late afternoon, they open out to be again at right angles to the sun; at sunset, they assume an upright "sleep" position. Leaves of plants under water stress or waterlogged also tend to maintain an upright position. Shaded leaves or all leaves on a heavily overcast day are more or less horizontal. After a rain, the leaves will remain horizontal even in sunlight and the petioles and leaflets may point downward rather than upward (179).

The pigeonpea grows and yields poorly under shaded conditions. After the plant reaches a height of 0.6 to 0.9 m, many of the shaded lower leaves and branches fall off. The leaf drop may amount to over 2 metric tons/ha, containing over 30 kg N.

Though the pigeonpea flowers profusely, many buds drop and the majority of developed flowers also fall. Of the young pods which develop from the 10-20% remaining flowers, many abort and fall. Lower and middle branches (older) bear more pods than upper (younger) branches. The lower part of a branch flowers before the upper part. A higher proportion of the more basal flowers form pods (179). Flower production and pod set are at the maximum during the first three weeks of the flowering phase (220).

Pods developing from the earlier-formed flowers tend to inhibit development of pods from later flowers. Removal of earlier-formed flowers leads to an increase in pod-setting from late flowers which would otherwise have dropped off. The pigeonpea plant has the ability to continue to produce flowers and pods if earlier crops are damaged or lost, providing favorable rains occur (179).

Manual defoliation up to 50% in plants under stress has had little or no effect on pod production (65), but under normal growing conditions 67% defoliation has resulted in 57% reduction in yield. Total defoliation still allows the plant to produce 20% of its normal crop, of normal seed size and normal number of seeds per pod (179,180).

In several countries, selection and cross-breeding experiments are being conducted with a view to improving the characters of the plant for field eficiency, favorable timing and uniform ripening of crop, seed quality and disease resistance.

Natural crossing was investigated in Puerto Rico and averaged 5.8% in a population of 5,328 plants (1). Average cross-pollination between rows ranges from 3-28% (224). To avoid cross-pollination where Taeniothrips distalis is the main pollinating agent, a distance of 5.5 m is recommended between plots. If bees are common in the area, distance between plots must be increased considerably--186 to 360 m alley has been suggested (14). Where this space is not available and yet maintenance of seed purity is desired, it is proposed that, where plots adjoin, no harvesting of seeds should occur across a 9 m width of rows on the "contact" side of each plot (38), or the flowerbuds must be covered with fine-textured nylon bags or other suitable material (1).

Floral biology is being studied at the Ranchi Agricultural College, Bihar. Pollen grains were found to remain viable 42 hrs. at 25.28° C and relative humidity of 50.60%, and for 11 days when refrigerated at 10.55° C and 37.5% relative humidity (205). At Coimbatore, it appears that the optimum hours for cross-pollination are from 10 AM to noon (299).

ICRISAT has made a special search for types showing male sterility or heterostyly for use in outcrossing. Five types have been selected for distribution to breeders (225).

The ideal plant height for easy manual harvesting is between 1.2 and 1.8 m. Because of the high labor factor, the majority of growers prefer a high-yielding plant producing one main crop to be completely harvested over an 8-week period.

Joshi (131) maintains that the "Number of branches and number of pods per plant are the main yield components and should be viewed as selection criteria in this crop." Singh and Mall (268) declare that "clusters per plant is the most important yield component." Reddy et al (226) have recently determined that pod numbers and seed size have the greatest effect on yield. Wakankar and Yadav (304) reported that a high number of pods had the most direct effect on yield, followed by number of secondary branches and seeds per pod.

A study of inheritance factors at the University of Puerto Rico showed that plant height, flowering date and seed weight have high heritable values in contrast to number of seeds/pod and number of pods/plant (174).

Tall plant habit was found dominant over dwarfness in studies of 123 hybrids between strain CO1 and radiation-induced mutants of CO1 (260).

At Gwalior, India, spreading and compact types were tested in mixed crop and solo crop situations. In all cases, spreading types (particularly a local genotype and secondly Gwalior-3) produced by far the greatest number of primary and secondary branches and pods and the highest yield of seeds/plant (289). In an earlier trial of 600 plants from an F_2 population of Gwalior-3 X N.P.69 hybrid, plant spread had a negative effect on yield (304).

When cultivated commercially for seed, the pigeonpea is grown as an annual or biennial because productivity declines after the first year; drops considerably after the third year. When grown for forage or green manure it is usually maintained no more than five years. The plant will die in about 10-12 years.

No regrowth occurs in pigeonpea plants cut off at ground level, but regrowth is satisfactory with cutting heights ranging from 0.15 m to 1.5 m. Vigor declines and plant mortality increases somewhat after a first cutting and more markedly after a second cutting. For continuous regrowth and longevity, the pigeonpea requires high-level cutting by combine harvesters with minimum bruising (14).

Pests

Diseases: The primary pigeonpea disease in India is a wilt caused by the soil-borne fungus Fusarium oxysporum f. sp. udum (Butl.) Snyder and Hansen which affects the entire plant in the reproductive stage. There is a higher incidence of wilt in plants grown in unsterilized soil, and in those sown in the off-season (December in India). Fungistatic activity of microorganisms in soil and seasonal highs in fungistatics are being investigated at Gorakhpur, India (173).

Wilt is higher in ratooned plants than in those which have not been cut back. It has been controlled by the fungicides Benlate and Bavistin (273) and by rotating pigeonpea with cereal crops. Removal of flowers has prevented wilt in nearly all plants treated (179). Plants with sterility mosaic disease (which prevents or inhibits flowering) are wilt-free.

The sterility disease was first observed in India and Burma in 1931. It is now widespread in India, affecting 100% of the plants in some fields (182). In 1952, the disease was attributed to virus infection and named "pigeonpea mosaic." The vector was identified as an Eriophyid mite (Aceria cajani) in 1962. Completely diseased branches fail to flower; on partly diseased branches, the flowers do not set normal fruits (204). Nodulation is severely reduced in plants infected early (249). Maramorosch and co-workers (165) confirmed whiteflies as the carriers of yellow mosaic (Rhynchosia mosaic) in Puerto Rico but could not identify the "virus" microorganism and suggest it may be an as yet unknown viroid. Four lines (ICP-3783, 6986, 6997 and 7035) and one cultivar, Hy3C, are immune to the disease (183).

According to Abrams (2), there are no major disease problems in Puerto Rico, yet leaf rust, caused by Uromyces dolicholi Arth. or Uredo cajani, may result in severe defoliation. Attacks by Sclerotium and Phytophthora are of secondary importance.

Sclerotium rolfsii Sacc. is saprophytic on dead leaves and stem sections of bamboo grass or bull grass. It attacks stems and roots of pigeonpea seedlings between 27 and 45 days old. Many determinate varieties of pigeonpea in Trinidad are highly susceptible; but some semi-determinate types (10/246, 4/95 and 5/119) from India have shown considerable tolerance (35). Rooting out and burning the host grass reduces the incidence of the disease (37).

In the West Indies, collar and stem canker are caused by Diplodia cajani Raychaudhuri, D. cacaolicola P. Henn and Phoma sp. (22). Basal stem canker or charcola rot arising from Macrophomina phaseoli (Maubl.) Ashby may kill 2-4% of the plants in fields in Uganda (214). Phaseolus manihotis induces root and stem rot.

Anthracnose, caused by Colletotrichum cajani Rangel, may affect the leaves and pods and destroy the seeds during periods of heavy rainfall. Cercospora leaf spot (C. cajani P. Henn. and C. instabilis Rangel) and bacterial leaf spots may cause foliage shedding and reduce productivity of susceptible strains. Leafspot diseases, especially

Mycovellosiella cajani, are common in East Africa but are said to have no significant effect on seed yield (214).

Leaf shedding may occur from attacks of downy mildew, Leveillula taurica (Lev.) Arn. in humid weather (214). Powdery mildew (Oidium clitoriae) has recently been found on both surfaces of young leaves at the Millets Breeding Station, Coimbatore, India (181).

Witches'-broom disease caused by mycoplasma-like organisms, has been seen at several locations in the West Indies and is believed to be transmitted by leafhoppers (Empoasca sp.) (152,293). Pigeonpea rosette, also associated with MLO, is prevalent in Andhra Pradesh, India (164). Similar leaf distortions in the absence of microorganisms or viruses apparently are caused by leafhopper toxin.

Nematodes: The pigeonpea is generally held to be fairly resistant to infestation by rootknot nematodes. In the southern United States, it is resistant to the nematodes Meloidogyne incognita (Kofoid & White) Chitwood and M. hapla Chitwood; somewhat resistant to M. javanica (Treub) Chitwood and M. arenaria (Neal) Chitwood, but susceptible to the lesion nematode, Pratylenchus (128). In Puerto Rico, a nematode (Rotylenchus sp.) attacks pigeonpea root nodules, causing stunting of the root system and above-ground plant (41).

O'Farrill (187) studied the histopathology and pathogenicity of the nematode Rotylenchulus reniformis on pigeonpeas under greenhouse conditions. He also studied the life cycle of R. reniformis on pigeonpeas. A population of 100,000 nematodes was necessary to reduce plant height while 10,000 significantly reduced foliage and root dry weight. On a previous experiment, Ayala (41) found that a population of 10,000 nematodes significantly reduced plant height. These differences might be attributable to the use of different cultivars, to the possible variability among the R. reniformis populations and to soil and weather conditions. Nematode populations above 10,000 significantly reduced the number of root nodules.

Insects: Major pests of the pigeonpea are the larvae of the American bollworm (Heliothis or Helicoverpa armigera Hüb.), the gram caterpillar (Heliothis obsoleta F.), the tobacco budworm (Heliothis virescens Fabr.), the corn earworm (Heliothis zea Boddie), the velvet-bean caterpillar (Anticarisca gemmatilis Hüb.), the red gram plume moth (Exelastis atomosa W.), the pea pod borer (Etiella zinckenella Treitschke), the gram pod fly (Melanagromyza or Agromyza obtusa M.), also Maruca testulalis G., Clavigralla gibbosa Spin., Zonabris pustulata, the larvae of the pyralid moth (Elasmopalpus rubedinellus Zell.) and the blue butterfly (Lycaena boetica)--all of which damage pods and seeds in the field. In Puerto Rico, pod borers are not active during the principal fruiting season; only during the summer when cultivar Totiempo may be in bearing.

In the Virgin Islands, Spodoptera frugiperda J. E. Smith, Fundella pellucens Zell., and Apate monachus Fabricius are included among the pod and stem borers.

In India, over a long flowering and fruiting season, as many as 17 sprayings may be needed to combat pod borers (308). A 3-stage spray schedule (first an application of 0.87 endosulfan 35 EC, secondly, 0.1% malathion 50 EC, and lastly, 0.1% carbaryl 50 W.P.) at 15-day intervals has been found effective against Heliothis armigera (236). Since there are over eight species of pod borers attacking the crop in India, other methods of control have been sought. Experiments have shown that application of granular insecticides (cytrolane 10%, disulfoton 5%, bux 10%, carbaryl 2%, phorate 10%, or fensulfothion 5%) to the soil 45 days after sowing, gives good control (115).

In Puerto Rico, pigeonpeas are seriously affected by a relatively large number of insect pests (313,314,315,316) among which several species of Empoasca have been identified (165). Cotte (59), under conditions in Puerto Rico, studied the effect of leafhopper (Empoasca spp.) attacks on yields of 10 commercial cultivars of pigeonpeas. He observed the habits of the leafhopper adults as to selection of oviposition sites and nymphal distribution. He finally determined damage based on symptoms caused by leafhopper feeding under field conditions. Leafhopper feeding reduced yields; the magnitude of the reduction varied with cultivars. Carbofuran and Methomyl provided adequate control of the leafhopper. The level of resistance found in some cases, such as Line 148, was enough to protect the plant from slight or moderately low populations of Empoasca. This is important since the use of lines with some degree of resistance might permit a more effective control with reduced rates of insecticides. Cotte (59) observed that the most critical period for leafhoppers control was at pod setting and filling. Adults of Empoasca occur generally all over the plant while nymphs favor the undersides of leaves, not fully mature, on the upper portion of the plant. Egg deposition occurs primarily in younger petioles or leaves of the upper portion of the plant. Eggs are inserted into the tissues of the leaf petioles or in the leaf veins. A few eggs may be inserted into the leaf blade between the veins.

In Puerto Rico, pod borers are controlled by two applications of Endosulfan, 2.24 kg/ha, two weeks apart (2). Authorities in Trinidad recommend spraying with Gardona 25 EC (3.5 liter/ha) or Dipterex S.P. 92 (2 liter/ha) three times, three days apart, beginning when half the flowers are fading (35).

A new pigeonpea pest, Taraostigmaodes sp., was recently discovered at ICRISAT. A survey showed it to be widespread and abundant in five Indian states. The larvae attack the seeds and pods. Cultivars Hy-3A, Hy-3C, PS-71, ST-1, No. 1234, GC-6800-67, ICP-7035, and NP (WR-15), appear to be most susceptible. It was also noted that this new insect is itself host to a parasite (Paraholaspis sp.) (147).

Young plants may be injured by the red hairy caterpillar (Amsacta albistriga Wlk), the grasshopper (Colemania sphenarioides Bol., and Aphis craccivora Koch. Infestation by cutworms (Agrostis spp.) is at times serious in India but can be checked by spraying the soil and base of the plant with Thimet (phorate) suspension (132).

Nigerian plantings are often attacked by the Coreid bug (Acanthomia tomentosicollis Stål), the female of which lays eggs in batches of 5-75 mainly on the pods, to a lesser extent on the leaves (84). Laspeyresia pychora is another pest reported from Africa; the scale insect, Icerya purchasi in Angola. Ancylostomia stercorea Zell. is active in the West Indies (213). The leaf-eating flea-beetle (Diphaulaca sp.) has caused severe damage in rainy seasons in Trinidad. Lachnosterna jamaicensis is a major pest in Jamaica. In northern Nigeria and in Australia, pigeonpea stem base attack by termites has been prevented by dusting the bases with Dieldrin--2.25 kg active ingredient/ha (14).

In Mauritius, pods and flowers are attacked by 6 species of insects and 10 species feed on the leaves and young shoots, seriously affecting the success of pigeon pea cultivation (103).

In Hawaii, the most serious enemy of the pigeonpea plant is the soft elongated flat scale (Coccus elongatus Sign) which destroyed plantings of several hundred acres in 1931-32 (103). The black thrip (Taenothrips nigricornis Schmutz) has been observed in numbers on pigeonpea flowers in Uganda but there appears to aid in pollination instead of harming the blooms. This thrip and Frankliniella sulphurea Schmutz sometimes heavily infest the flowers in India and are responsible for "weak growth, drying and ultimately premature shedding of flowers and poor pod setting." Control has been achieved with .03% spray of Dimethoate, also a 0.02% of Endrin, and .03% Endosulfan (306).

The pulse beetle (Bruchus sp.) and a lesser pest, Trogoderma granarium, attack pigeonpea seeds in storage. Protective measures are application of Malathion to the sacks and fumigation of the seed with Ethylene dibromide, Phosphine or Methyl bromide (14).

The bruchid beetle, Callosobruchus chinensis (L.) has been observed in large numbers in the Agricultural Experiment Substation farm in Isabela, Puerto Rico. It has been found in treated seeds stored at 55-58°F and held on 6 months in storage. The seeds may be infested in the field before harvesting. It has been observed that the female bruchid oviposites on partially dried pods, covering the egg with a transparent gel which hardens and becomes opaque in a few days. The larva emerges under the protective cover, and bores its way through the pod into the seed.8/

CROP AND SOIL MANAGEMENT

Propagation and Germination

The pigeonpea can be reproduced from cuttings but is usually propagated by seed, which germinates well when fresh, though in some cultivars there has been noticed a slight improvement in germination after holding

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8/ Lugo-López, Aurora, (ret.), University of Puerto Rico, Mayaguez Campus, Unpublished data, 1981.

for 85-95 days. Seeds 4 years old have shown 80-100% germination: 9-year-old seeds, from 0-65% (14). However, Suard and Degras (282) have reported that, in Guadeloupe, at room temperature, pigeonpea seeds decline rapidly in viability after 4 months from harvest (possibly because of seed-borne fungi). Cold storage at 6-12° C extends germination life for over a year (282).

Under favorable conditions, it is not unusual to achieve 95% germination in the field, providing the seed is set at 5 cm depth (2-5 seeds per hole). In the common practice of broadcasting, many exposed seeds may be lost in dry weather. In a season of low rainfall in Kenya, seeds were placed (dibbled) at a depth of 2.5 cm ; many that germinated soon died from dehydration (136). At the other extreme, when deep-drilled into the soil, seeds at depths of 10 cm have failed to germinate (112).

Field Preparation

The field may be manually hoed or, where appropriate machinery is available, plowed, disked and harrowed to a depth of 20 to 22.5 cm. If there is danger of soil erosion, shallow tillage is recommended as well as leaving a layer of mulch on the surface. The latter aids also in lowering soil temperature and maintaining desirable moisture. If the field is not well drained, ditches should be dug at regular intervals to achieve uniform drainage. Pigeonpeas need not be planted on ridges unless waterlogging is apt to occur in the early stages of growth. Under such conditions, ridging has increased yields by 30% (14).

Spacing

When interplanted with other crops, the pigeonpeas are usually 1 m apart with 1.5 m between rows, giving a density of 6,970 plants/ha (309). Various experiments have shown that, in solid plantings, row-spacing facilitates cultivation and produces higher yields than broadcast sowing. Distance between plants in single-crop fields usually varies from 30 to 60 cm and between rows from 45 to 90 cm , depending on the habit of the type grown and the fertility of the soil (298).

In India, row spacing of 120 cm with 60 cm between plants is recommended for long-duration varieties; 50 to 75 cm between rows and 20 to 30 cm between plants for short- and medium-duration varieties; row-spacing of 30 to 45 cm with a density of 100,000 plants/ha for extra-early and compact varieties (252).

Determinate semi-dwarf or dwarf types (mean plant height 70 cm) in Puerto Rico at 143,318 plants/ha have produced 5,000 kg / ha green pods (3).

Higher density--165,000 plants/ha--of determinate dwarf cultivars planted in December in Trinidad reduced plant height to about 1 m, highly desirable for mechanical harvesting. The yield was 2,544 kg/ha green pods. The shortened growing season (110 days) would permit two crops to be harvested annually (275).

In a spacing/planting-date trial in Trinidad, two dwarf lines, CH 11/33/34 and GI 27/4a, were planted in May, June and July at three different spacings. The closest spacing (0.25m^2/plant--equivalent to 39,800 plants/ha) reduced the per plant yield but gave the greatest yield, nearly 8,000 kg/ha from two harvestings of green pods. Time of planting had little effect except that early planting date together with close spacing increased plant height (109).

In Queensland, a field of UQ1 sown in October at a density of 17,940 plants/ha, spaced at 0.914 X 0.610 m, gave the highest oven-dry seed yield--2,744 kg/ha (12). At a density of 107,639 plants/ha, UQ1 spaced at 0.305 X 0.305 m, produced the greatest amount of dry material--22,950 kg/ha. Dry matter yield declines at higher density (12). UQ50 sown in late January at a density of 220,000 plants/ha and irrigated, yielded 5,300 kg/ha dry seed in a single, second harvest.

Yield was lower when this cultivar was set at 400,000 plants/ha[9/].

Time of Planting

In Queensland, optimum sowing times were identified as late November to mid-January for dry seed production in late-maturing pigeonpeas, and not later than December for "periodic green pod picking in the early-maturing types" (12).

IITA recommends that, in general, pigeonpea should be planted 2.5 to 3 months before the end of the rainy season.

Planting of short types may be done any month of the year (in Puerto Rico, preferably October-December; in Trinidad, Nov. 15-Jan. 15) but the flowering of tall types occurs in the period of short-day length; thus depending on planting time, flowering of these may take place as early as 125 days or even as late as 430 days from seed (137). In Puerto Rico, early planting (April-June) has been found most favorable for the Kaki type (3).

Trials of Kaki in Sao Paulo Brazil, at 6 planting dates, revealed minor variation in flowering time when seed was planted in October, November and December, but the number of days progressively increased in January, February and March plantings. October seedlings were tallest; those of March, shortest. Best results (1.69 m height and good yield) resulted from planting in January (155).

In the Punjab, dry seed yield of T-21 is superior in plantings made from June 1-15 to those made June 30-July 15 (133).

Thinning and Replacement

For best development, thinning to one seedling/hill is considered essential between 4 and 9 weeks after planting. Many farmers err in leaving 3 to 4 plants/site (117).

9/ Wallis, E.S., Univ. Queensland, St. Lucía, Personal communication, 1977.

A nursery plot of extra seedlings can be useful for replacing plants lost for any reason. Transplanting should be done 4-7 days after emergence.

Weed Control

Initial growth of the pigeonpea is very slow and weed control during the first 4-8 weeks is necessary. If hand-weeding is the only method possible, it should be done with care 1-15 days after planting, repeated 25-30 days after planting, and again 40-50 days after planting (27). Within 2 months, the plants will have grown sufficiently to shade out weeds.

Chemical weed control has significantly increased green pod yield as compared with no weed control, hand- and mechanical weeding. The most successful herbicide for pigeonpea plantations in Puerto Rico has been found to be Prometryne (commercially Caparol), applied at the rate of 3.33 kg/ha (4). Gesaprim 80 (Atrazine)--2 1/2 kg/ha--has given good results in Trinidad (37). At Pantnagar and Coimbatore, India, Nitrofen, or TOK--1 kg a.i./ha--has been superior to other preemergence herbicides (293). In greenhouse trials, Dacthal (Chlorthal dimethyl)--6.75 kg active ingredient/ha--has controlled grass without injuring pigeonpea. Treflan (trifluralin) stunted and deformed seedlings even at low-level applications (305). If occasional weeding is necessary after the plants are 45 cm tall, Paraquat (Gramaxone)--1.18 liter/ha--can be utilized but is not recommended inasmuch as Paraquat is a general herbicide, orally toxic and a possible hazard to humans.

Irrigation

After the first 8-12 rainfed weeks of growth, the pigeonpea is remarkably drought-tolerant and resists several months of dry weather until rains resume. Supplemental irrigation is rarely needed, but has been resorted to at Kimberley in Western Australia and Ituri in the Belgian Congo (14). At Hyderabad and Bhavanisagar, India, pigeonpeas planted in the dry season have shown good response to irrigation (253). The pigeonpea will not tolerate excess water, which causes seed decay and retards plant growth.

Disease and Insect Control

In the pre-flowering stage, insects are seldom troublesome. After flower initiation, it may be necessary to spray an effective insecticide at least 2 to 4 times at 7- to 10-day intervals. General insecticides which have given good results include Azodrin (monocrotophos) 60 EC--0.5 kg/ha, or 2 ml/l of water; Gammalin 20 (lindane or gamma BHC); Thiodan (endosulfan); and Didigam (DDT with gamma BHC) (27).

In Trinidad, the stumps are usually cleared from the field and destroyed at the end of each completed harvest as a sanitary effort to eliminate diseases and pests.

Growth Regulators

In Jamaican experiments, Ethephon had a positive effect on rust-susceptible cultivar 20 when in flower. By inducing "a sudden total loss of leaf, followed by rapid production of new leaves" and then a second flowering, Ethephon "effectively enabled the plants to 'evade rust'". Pod number increased but there were fewer seeds/pod (112).

At IARI, tests were made with foliar sprays of TIBA in concentrations of 25, 50, 100 and 200 mg/ml. Application of the 100 mg/ml spray gave the best seed yield, a 21% increase over the control, but it is not known what physiological effect caused the increase (44).

Rojoa (232) used Triacontinol, a growth hormone, as a subtreatment in a fertilizer experiment. It had no effect on grain yield. Its effects on growth and N content were short lived.

FERTILIZATION

Nutrient Uptake

The uptake of nutrients by crops is a function of its growth and dry matter production. It provides a sound indication of potential nutrient requirements. A crop of pigeonpeas producing 1830 kg/ha of dry matter would take up 32 kg N, 10 kg P, 11.1 kg K, 13 kg Ca and 5 kg Mg (168). Rao (232) found that a crop of pigeonpeas, cultivar Pusa Ageti, yielding 2 T/ha of grain and 6 T/ha of sticks, removed 132 kg N, 25 kg P_2O_5, and 64 kg K_2O/ha.

Dalal (67) reported that total N, P, K, Ca and Mg contained in pigeonpeas yielding 5280 kg/ha of green pods and grain was 198, 17, 53, 43 and 31 kg/ha, respectively. Irizarry and Rivera (125) report that pigeonpeas grown on a typical Ultisol of the humid region of Puerto Rico took up an average of 216, 12, 168, 54 and 19 kg/ha of N, P, K, Ca and Mg, respectively, over a planting-to-harvest cycle of 147 days. Total dry matter production and yields of mature-green pods and grain were 12,340 and 8,104 kg/ha, respectively.

Variable Response to Fertilizers

On the basis of the relatively high nutrient removal (168), including pods, seeds and the whole plant, it could be logically inferred that the demand for plant nutrients of the pigeonpea crop is correspondingly high. Consequently, a crop response to applied fertilizers would be normally expected in soils of low inherent fertility. However, such is not the case in many pigeonpea producing areas. The pigeonpea is considered to be an exhausting crop that uses rather large quantities of N. Through its relatively high biological N fixation rate it can obtain enough N to supplement the N which can be provided by the soil from the reserves of soil organic matter and root residues. The deep and profuse root system of the pigeonpea allows it to tap more successfully a larger soil volume than do some other cultivated crop plants.

All together, these can contribute N in substantial amounts. Furthermore, under such conditions, little or no response to N fertilizers is likely to be expected (157).

The pigeonpea is not ordinarily fertilized by farmers. The International Institute of Tropical Agriculture (IITA), advises the broadcasting of fertilizer and working it into the soil before planting in order to assure minimal requirements of specific plant nutrients. The formula, 25 kg N, 25 kg P (60 kg P_2O_5) and 25 kg K (30 kg K_2O/ha) is recommended for IITA for all types of soils.

Agronomists at the University of Florida made experimental plantings on a dry sandy soil at Gainesville and felt that results warranted recommending 55-186 kg of 0-3.4-6.6 or 0-4.3-8.3 N-P-K fertilizer/ha at seeding time "though pigeonpeas are not too demanding of special nutrition" (139).

It has been reported that the pigeonpea, planted alone, has failed to respond to 22.4 kg N/ha. The application of this amount of N to a field of pigeonpea intercropped with millet reduced the yield of pigeonpea possibly by increasing the competition of the millet or perhaps due to the inhibitory effect of N on the N-fixation capacity of the Rhizobium (14).

In pot culture, it has been observed that N alone or combined with K or P has reduced the number, yield and N content of pigeonpea nodules (139).

In South Florida's limestone soils, Stambaugh (280) claimed that vigorous vegetative growth of fodder could be attained only by applying 800 kg of fertilizer/ha--1/4 at time of planting (January or February), 1/4 in July and 1/2 in September. He specified a formula containing 4% and 8% each of P and K_2O as well as micronutrients (279). Later, he reported that best seed yield was obtained with no N, 2,000 kg raw rock phosphate, 1,000 kg ground dolomite, 150 kg sulphur, 400 kg muriate of potash, 20 kg sulfate of copper, 29 kg sulfate of manganese and 20 kg sulfate of iron/ha (280).

Concurrent trials were made in two different districts of Puerto Rico--one with cultivar Kaki in Yauco clay on soft limestone, arid hills and the other with cultivar Vaininegro in Coto clay in slightly acid undulating terrain. Coto clay (Oxisol) is known to require high levels of N and P for satisfactory yields in sugarcane. Applications of N (ammonium sulfate) ranging from 75 to 225 kg/ha (together with P and K) gave no significant increase in yields over the unfertilized controls at either site (145). In subsequent trials with cultivar Kaki in Coto clay, no difference in yield or protein content was achieved by applying 43.5 kg/ha of N in various mixtures with P, K, Ca, Mg and with and without calcium silicate (201). Two recent trials of foliar application of N and P fertilizer to cultivars Kaki and 2B-Bushy planted on Coto clay yielded no significant differences in plant height, protein content, seed weight of seed:pod ratio as compared to unfertilized plants (42).

In sandy loam laterite soils at Bhubaneswar, India, added N up to 20 kg/ha increased grain yield of cultivars S5, T-21 and R-60 by 190 kg dry seed Ha. Higher N applications (40 kg/ha) depressed grain yield (149).

Rojoa (232), working recently under conditions at Trinidad, applied fertilizer N at a rate of 50 kg/ha in two equal split applications: one at planting and a second at 40, 50, 60, 70 and 80 days, respectively, from seedling emergence. A 46% increase in grain yield was obtained when a second split was given at 40 days; delaying the second N application reduced grain yield. When the rate of N was varied from 0, 20, 40, 60 and 80 kg/ha, it was found that a rate of 60 kg/ha, it was found that a rate of 60 kg/ha was conducive to a 71% yield increase. In other trials, Rojoa (232) found that urea was more effective than sodium nitrate, ammonium chloride and ammonium nitrate in terms of both growth and grain yield. Ammonium chloride at a rate of 50 kg/ha of N had an adverse effect on germination.

It is now generally accepted that, at some locations, small initial applications of N may boost early growth of the pigeonpea, improve nodulation and enhance yield.

Researchers in Trinidad have stated, without reporting details, that when N was applied late in the season it elevated the protein content of the seeds (35).

In a K experiment, varying from 0, 20, 40, 60, and 80 kg/ha, it was found that growth and yield of pigeonpeas increased with increasing fertilizers K up to 60 kg/ha beyond this level, both growth and grain yield decreased (232). During this experiment, some plants suffered from a mineral deficiency diagnosed to be B. As a result, a micronutrient experiment was conducted with Zn, B, Mo and Cu. Zn gave an increase of 26% in yield. Cu and Mo treatments showed an increase of N content in plant tissue.

Biological N Fixation and Release

Less than half of the world's potentially arable land is now under cultivation. Five hundred million hectares of underutilized, deep, well-drained, potentially arable land lie in the humid tropics and subtropics (291). Most tropical soils, however, are deficient in certain nutrients. Fertilizer prices have gone up considerably since 1973 and will inevitably continue to rise. Farmers are unwilling or unable to pay higher prices as well as the costs of transportation which may be excessive when agricultural developments are far from industrial centers. Reduction in fertilizer use is already having a negative effect on production.

Commercial manufacture of N consumes great amounts of fossil fuels and energy. Leguminous plants are noted for their ability to fix atmospheric N in root nodules through symbioses with soil bacteria of the genus Rhizobium. Some legumes fix more N than they require for growth and production and, therefore, contribute N to the soil in which they grow.

Legumes are generally of higher protein content than the usual staple foods of the tropics--cereals and roots or tubers--but legume yields are nearly always low compared to cereal yields/ha (roughly 25% less). For these reasons, programs designed to enhance the biological fixation of N and increase the productivity of legumes should have a positive impact on soil utilization and human nutrition in the subtropics and tropics.

Most of the important tropical legumes nodulate freely without inoculation under optimum conditions. Some legumes have special requirements for inoculation when introduced into areas where they do not naturally occur. Indigenous rhizobia, even when abundant, may be less effective than selected strains that could be introduced if methods can be found to successfully replace established species.

No information is available in the literature concerning the frequency of inoculation of pigeonpea seeds.

Pigeonpea not Inoculated with Rhizobium

The pigeonpea plant takes up N continuously to maturity. Young plants are more effective in the fixation process than older ones. The N level increases in leaves up to flowerbud initiation and remains constant thereafter. In the stems, N increases slightly after flowerbud initiation. The total uptake by reproduction structures is much more than by leaves and stems (179).

N fixation of pot-grown pigeonpeas in washed sand fed with N free nutrient solution has been determined to be 14.5 mg/plant/day in contrast to 10.3 for Centrosema and 4.6 mg for Stylosanthes. From 70 to nearly 100% of the N was transferred from the nodules to the rest of the plant soon after fixation (188).

In a 3-year field study at New Delhi, uptake of N and N-fixation by cultivar NP51 increased by application of 40 kg N and 120 kg P/ha. Total N uptake by the fertilized crop amounted to 330 kg/ha the third year as compared to 310 kg/ha in the control plots. Loss of N from the NP fertilized field in the first and second years was 40 kg/ha and in the third year 80 kg/ha, thus demonstrating that the pigeonpea is an exhausting crop. This loss could be compensated for and there could be some enhancement of soil N if the 7,177 kg/ha of shed leaf and flower material were incorporated into the soil, since the N in this material was calculated to be 131 kg/ha (256).

At ICRISAT, Hyderabad, nodule formation was studied in five cultivars (T-21, Pusa Ageti, ST-1, ICP-1 and Hy-3C) without inoculation and without N fertilizer. It was verified that nodules are not confined to the upper 15 cm or so of the root system. The majority were found in the first 30 cm. Small nodules were fairly common in the 120-150 cm zone and some occurred even further down. Up to 35% of the nodules were actually in the lower zones.

Nodulation was observed within 10 days of germination on all five cultivars. In red soil (developed from ancient granites), elongating branching nodules developed and continued to grow to large size. In a black soil (Vertisol), relatively small, spherical nodules were found, and degenerating nodules were frequently observed, suggesting that the life span of these nodules was relatively short and that new nodules were initiated and older nodules died throughout the early growth of the plants (179). This senescence is attributable in part to attacks by a grub which eats the cortex of the nodule, leaving it hollow. Some 80% of the nodules may be dead in 30 days (70).

Large seeds made better early growth than small seeds because of reserve material. At first, seedlings from smaller seeds or half seeds showed more nodules; later, nodulation was in proportion to seedling size; faster growing seedlings with more leaf area have more nodules. Nodule numbers decline before the period of maturity, and also during moisture stress (35). No nodules at all have been seen on pigeonpea roots after 12 weeks of growth. In some plants they are totally absent after 8 or 9 weeks (256).

Harding et al. (116) compared nodulation of several legumes grown on an Oxisol in northwestern Puerto Rico over an 81-day period. Pigeonpeas were only second to winged beans (Psophocarpus tetragonolobus), a food legume widely recognized for its prolific nodulation. Numerous large active nodules were observed in pigeonpea throughout the experimental period. However, the number of nodules decreased with time, but the mean nodule dry weight increased. It does seem certain that growth of individual nodules is the dominant factor in the prolific nodulation of pigeonpeas, whereas growth in numbers as well as nodule growth is important in the abundant nodulation of winged beans.

In test plants where pod development was prevented by flower removal, there was no evidence, that this elimination of competition enhanced nodule development. In fact, nodule numbers progressively declined both in these plants and in the controls (179).

Various factors (cultivar, planting date, density, soil, weather, diseases and pests) apart from nodule formation, may affect yield.

Trinidad yields of full green pods have ranged from approximately 200 kg/ha for healthy but unimproved cultivar to a maximum of 9,500 kg/ha using improved cultivars in pure stands. The conversion ratio of fresh full green pods to dry shelled peas is 3.35 to 1 (118).

Yield of dry seeds in uninoculated pigeonpeas usually ranges from 400 kg/ha to 1,086 kg/ha. The average yield in India from 1908 to date, is about 600-700 kg/ha. Exceptionally favorable conditions have resulted in a remarkably high yield of 5,000 kg/ha of dry seeds (214).

Pigeonpea inoculated with *Rhizobium*

The unspecialized cowpea-type *Rhizobium* is so widespread in tropical soils that it has been commonly believed that legumes of the cowpea group rarely respond to inoculation but are nodulated effectively by naturally occurring soil rhizobia from a range of leguminous genera (72). However, pigeonpeas sown after rice at ICRISAT showed nodulation enhancement due to inoculation and various experiments are revealing that deliberate inoculation of pigeonpea seeds with selected strains of *Rhizobium* has a significant effect on the yield of grain and dry matter and their constituents.

Methods of Inoculation

Without Chemical Seed Treatment: Peat is the preferred carrier for *Rhizobium* because it accommodates large number of bacteria, helps maintain their viability and adheres well to seeds. In Puerto Rico, testing of coir dust as a carrier showed rapid decline in rhizobia which has been attributed to the tannin content of coir (30). Detoxification is necessary in order to use this material as a vehicle for inoculants.

An effective strain of *Rhizobium* can be introduced into the soil by watering it into a furrow below the seed or by pouring it over the planted seed before covering with soil (218).

There are two principal methods of applying bacteria to the seed: 1) dry method--dusting the seed with a peat or humus culture; 2) wet method--applying a slurry of peat, agar or freeze-dried culture in water or sugar solution, and then drying. It is feared that this wet method may release chemicals from the legume seed coat which are toxic to the rhizobia.

Seed inoculation may be improved by inclusion of an adhesive (usually gum arabic or methyl ethyl cellulose). A protective layer of finely ground phosphate (bauxite), lime, talc or charcoal is often used on pigeonpea seeds in India. Such pelleting is particularly important in avoiding loss of Rhizobium when inoculated seed is mixed with acid fertilizer, and it may also give the Rhizobium at least temporary protection from other unfavorable conditions.

Commercially inoculated seed may be deficient in rhizobia bacteria. Batches of pigeonpea seeds tested at the Australian Inoculant Research and Control Service (AIRCS) in 1972-74 showed very low bacteria populations as compared with laboratory standards which require at least 100 million bacteria per gram of peat, resulting in 600-10,000 micro-organisms spread over the surface of each seed. The commercial samples tested usually had less than 1% of the rhizobia desired. The fault may lie in the drying process. High temperatures during drying and in storage cause rapid losses in bacteria. Rhizobia counts fall swiftly in the first 6 to 8 weeks of storage. AIRCS investigators have recommended that the date of preparation be displayed on all commercially preinoculated seed (288). High soil temperatures, especially in clay and soils low in organic matter, can also reduce the numbers of rhizobia (69).

The highest quality peat inocula commercially available at this time very rarely contain more than 1,000 million rhizobia/gram of peat. Some manufacturers are seeking means of increasing this count in order to assure adequate populations on preinoculated seeds. Commercial pelleting is handicapped in some countries by legislation which restricts the amount of foreign matter that can be added to seed for sale. However, if special permits could be obtained, commercial pelleting might go a long way toward maintaining rhizobia count and more satisfactory results for the farmer (49).

With Chemical Seed Treatment: Legume seeds are commonly treated with fungicide in order to control seedling diseases. It has been noted that light-brown pigeonpea seeds have a higher percentage (78.7%) of seed-borne fungi, compared to dark-brown seeds (53.77%) (274), which are higher in phenol content. Fungicides are to some degree toxic to *Rhizobium*. Experiments at the Plant Protection Research Institute, Pretoria, showed that the fungicides Brassicol, Terracoat L205, and Thiram 50 were the least toxic when applied to cowpea seed before inoculation with rhizobia in peat. When incorporated into the peat, Thiram was markedly toxic (292).

The antibiotic, Aureofungin, at 100 p/m, applied to pigeonpea seeds for one hour prior to sowing reduced wilt disease considerably. Application 6 hours in advance caused moderate phytotoxicity; 24 hours in advance, severe phytotoxicity (210).

Pigeonpea seeds distributed by the International Institute of Tropical Agriculture (IITA) for trial in various regions are treated with the fungicide Demosan (chloroneb) 65 WP. Inoculant is sent with the seeds together with instructions for applying it.

Much attention is being given the selection of effective *Rhizobium* strains which can survive in peat treated with fungicide (281).

Strains of *Rhizobium*

Forty-five *Rhizobium* strains have been isolated from pigeonpea plants grown in soil cores collected throughout Trinidad (35). Certain strains of *Rhizobium* are attracted to the particular exudate of specific plants and not to others. Pigeonpea cultivars grown in the same soil type differ in dominant *Rhizobium* strain forming nodules on the plant. The Indian cultivar, UF3104, appears to select a *Rhizobium* strain markedly different from that associated with tall and dwarf cultivars (36). Certain strains of *Rhizobium* may be attracted to the roots of legumes which they do not nodulate (64).

Greenhouse trials at the Rothamsted Experiment Station, England, using Trinidad Dwarf No. 5 pigeonpea and fourteen *Rhizobium* strains (13 from Africa), showed the following results: Strain 5008 and

CB 1024 (poor nodulation); CB756 (very poor); 5005 and 5030 (poor to medium); 5009, 5200 and 5029 (medium); 5018 and 5028 (good). Strains 5000, 5011, 5016 and 5017 failed to nodulate. The inoculated seeds were sown in sand-grit rooting medium flushed daily with a nutrient solution containing 25 p/m N as nitrate, with care to prevent cross contamination. Uninoculated control plants showed no nodulation (71).

In field trials at the International Agricultural Research Institute (IARI), New Delhi, inoculation with Rhizobium strain Arhar U was successful (281).

Strain CB756 is seemingly effective and is recommended for pigeonpea UQ38 in Australia but it is not known whether nodulation is actually the result of inoculation by this Rhizobium or by naturally occurring strains in the soil. This problem is being investigated (72).

Responses to Inoculation

Changes in Color of Crop: The pigeonpea rarely, if ever, shows signs of N deficiency in the field because of the prevalence of indigenous rhizobia. Deliberate inoculation does produce a color change (yellow to green) in the plant in greenhouse experiments.

Changes in Composition of Crop: At Coimbatore, isolates were made from 110 root nodules of pigeonpea collected at various locations and 64 isolates which made profuse growth were selected for pot culture trials. Five disinfected seeds of pigeonpea strain SA1 were sown in sterile sand in each pot and one ml of rhizobial suspension was poured over each seed before covering. After the usual care for 60 days, the plants were lifted, dried and analyzed. It was found that 53 of the isolates increased N fixation and dry matter yield/plant. The amount of N fixed varied from 1.3 to 342.3% over that of the controls (218).

Increased Yields: Pigeonpea strain UQ38, a tall, indeterminate type naturalized in Australia, gave high seed yields when inoculated with Rhizobium strain CB756. Six plantings made at approximately 4-week intervals from September 1, 1970 to January 19, 1971 gave dry seed yield/ha ranging from 3,052 kg to 6,021 kg. The yield declined markedly in crops sown February 16 and March 16 (305).

In a 2-year field experiment at Pantnagar, India, inoculation with Rhizobium cultures (5,000-6,500 viable rhizobial cells/seed) resulted in maximum dry seed yields of 1,560 kg/ha compared with a high of 1,240 kg/ha for uninoculated controls. Higher grain yields (up to 1,760 kg/ha) were obtained by pelleting the inoculated seed to protect the rhizobia. Pelleting material was talc, charcoal or lime. Control plants were nodulated by natural rhizobia in the soil, the nodule count plant ranging from 16.6 the first year to 25.8 the second year, compared with a maximum of 45.3 nodules on roots of plants grown from inoculated and pelleted seed (252).

Fertilizer P

Most studies indicate that P is the first limiting nutrient for pigeonpeas under the tropical environment (184). Under conditions in Puerto Rico, no response in pigeonpea yields have been measured attributable to applications of P (42 145,201). A plausible explanation might be found in the work with various crops of Bonnet et al.[10/], del Valle et al.[11,12/], and Badillo[13/] under various soil conditions.

10/ Bonnet, J.A., Capó, B.G., and Riera, A.R. 1946. Lack of response of sugarcane to applications of phosphorus in Puerto Rico, J. Agr. Univ. P.R. 30(3):180-95.

11/ Del Valle, R., Fox, R.H., and Lugo-López, M.A. 1977. Response of soybeans grown in an Ultisol to residual broadcast and banded P fertilizers, J. Agr. Univ. P.R. 61(2):179-86.

12/ Del Valle, R., Scott, T.W., and Lugo-López, M.A. 1981. Variable response of food crops to banded and broadcast residual P on an Ultisol, J. Agr. Univ. P.R. 65(2):

13/ Badillo-Feliciano, J., Lugo-López, M.A., and Scott, T.W. 1979. Influence of cultivars, N levels and time of N application on plant characters, leaf composition and yield of corn on an Oxisol, J. Agr. Univ. P.R. 63(3):273-80.

Even on Oxisols and Ultisols, tropical soils which are usually low in fertility, no crop response to fertilizer P could be measured. Del Valle et al.[11/] could not obtain any response from soybeans to applications of fertilizer P at varying levels. Under the same soil and climatic conditions they failed to obtain responses form 2 succeeding crops of native white beans[11/]. Many soils of Puerto Rico, whether planted to sugarcane, tobacco, coffee or pastures, have been receiving over the years rather large applications of fertilizer P. Most of this P has probably been fixed and can be gradually tapped by growing crops over a number of years.

Some experiments at the Indian Agricultural Research Institute (IARI), have indicated that broadcast P is readily available to the absorbing upper root system of the pigeonpea and, with this crop in sandy loam under irrigation, the broadcast method has been declared superior to deep placement of P (133). In more recent tests of cultivar Pusa Ageti in sandy loam under rainfed conditions, placements of N and P fertilizer at depths of 15 and 30 cm gave higher seed yield than surface application. Highest yield was obtained when half the fertilizer was placed at 15 cm and half at 30 cm depth (9).

Fertilizer K

The case for K under conditions in Puerto Rico can perhaps best be argued on the basis of the low K consumption while the K-supplying and releasing power of many of the soils of Puerto Rico can be rather high. Abruña et al.[14/] measured the K-supplying power of 23 typical soils by cropping pangolagrass on pots for 4 consecutive years. During the first

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14/ Abruña, F., Vicente-Chandler, J., Figarella, J., and Silva, S. 1976. Potassium supplying power of the major Ultisols and Oxisols of Puerto Rico, J. Agr. Univ. P.R. 60(1):45-60.

year of cropping, the soils released the following amounts of K:

Soil	K released, kg/ha
Oxisols	234
Ultisols of the upland	260
Ultisols of the coastal plains	230

After the first cropping year, K removal dropped off sharply to about 50 kg/ha for the Oxisols and Ultisols of the coastal plains and 90 for the Ultisols of the uplands.

Considering the relatively low K uptake and K removal in a pigeonpea crop (around 2 kg/ha/1000 kg crop) it can be inferred that most soils can release adequate amounts of K to support growth and production of pigeonpea crops throughout several years. Furthermore, K in soils where micas are abundant in the clay fraction and where the K-bearing minerals in the sand fraction are more abundant and less weathered, can be expected to become available throughout the years. Abruña et al.[12] measured removal of soil K by pangolagrass over 4 years of consecutive cropping of the order of 533 kg/ha, a figure that considerably exceeded the so-called "available" K content in the soil.

The Case for Ca and Mg

Lugo López and Abrams (157) state that most of the soils of Puerto Rico where experimental work with pigeonpeas has been conducted appear to be well-supplied with Ca. Even many of the acid soils with low exchangeable Ca can normally supply enough Ca as a nutrient for adequate crop growth. An Oxisol at Isabela, in northwestern Puerto Rico, with a CEC of 13 meq/100 of dry soil will have 3.6 meq of exchangeable Ca. This is equivalent to 1440 kg/ha of exchangeable Ca, which is more than enough to support many crops like pigeonpeas that use and remove only around 2 kg/ha/1000 kg crop.

The pigeonpea appears to use a relatively small amount of Mg i.e., 1.3 kg/ha/1000 kg of dry matter. The same Oxisol previously mentioned where pigeonpeas are grown in northwestern Puerto Rico, can supply almost 1 meq of available Mg/100 g soil. This is equivalent to 269 kg/ha of Mg, more than enough to support a number of crops for a rather large period of time (157).

Fertilizer Placement

Sheriff and Rajagopalam (261) have shown that when fertilizer N is placed directly under the seed in dry land conditions, germination is inhibited and seedling mortality increased. The damage is minimized when the fertilizer is placed in a furrow adjacent to the seed. In the case of fertilizer P placement in bands is not superior to broadcasting (261), although Saxena and Yadav (253) claimed the opposite.

TRANSFER OF NITROGEN TO OTHER CROPS

Leaf fall can contribute appreciably to N in the soil. According to Dart and Krantz (71), leaf fall might be as much as 2200/ha in a medium duration monocrop. With an average of 1.62% N, the leaf fall might return 39 kg/ha of N to the soil.[15/]

In Intercropping Systems: While the pigeonpea replaces and often adds N by shedding leaves and flowers, its deep root system cycles nutrients other than N from deeper soil to the surface to the benefit of other crops.

Traditionally, the pigeonpea is rarely sown with its companion crop in lternate rows--often pigeonpea rows are separated by 4-10 rows intercrop. Late-maturing pigeonpeas are usually planted together with sorghum, pearl millet, cotton, or with other legumes of short duration, and minor millets. In Central India, pigeonpea appears in monsoon cropping patterns in shallow, medium-textured, moderately deep black soil as follows:

Sorghum + pigeonpea + sesame (intercropped)

Pearl millet + pigeonpea + sesame (intercropped)

15/ Narayan and Sheldrake, 1976, ICRISAT, Unpublished data.

Intercropping experiments at ICRISAT, Hyderabad, with pigeonpeas planted at 75 cm row spacing and the intercrop between these rows, showed that the aggregate yield of the intercrops (cowpea, soybean, sorghum, pearl millet, Italian millet) was "about double that of the same species as sole crops sharing the same total area as the intercrops" (250). Interplanting peanut (groundnut) with pigeonpea cultivar Co-1 (#1141) reduces peanut yields 9-15% but provides a net profit greater than raising peanut alone (39). Peanut TMV2 planted as a sole crop has produced 1,991 kg/ha (unshelled); interplanted with pigeonpea, 1,965 kg/ha. The pigeonpea crop provides an additional 595 kg/ha of dry seeds (297).

Pigeonpea and cowpea together have given a total yield of 2,836 kg/ha. Mixed plantings of mungbean and pigeonpea have given yields of 1,226 kg to 2,636 kg/ha. Pigeonpea and black gram (urd) combined have yielded 1,119 kg/ha (250).

In Uganda, pigeonpeas are frequently grown in mixed plantings with sorghum, finger millet, peanut (134) or sesame (132).

Some cultivars of pigeonpea show abnormal growth habits when intercropped. ICP-1 and Hy-3C do not develop basal branches when grown in alternate rows with pearl millet which tends to shade the pigeonpeas (69).

Maize (except dwarf maize) and sorghum also reduce pigeonpea yields by providing too much shade. Nevertheless, the majority of the farmers in Trinidad plant maize as an intercrop simultaneously with pigeonpea. The maize is harvested and the stubble removed just before the pigeonpea bushes bloom. At the same time, cassava may be interplanted, succeeding the maize, in order to have a third crop ready after the pigeonpeas have been harvested and the bushes removed. Other crops grown among pigeonpeas by many Trinidad farmers include okra, tomato, pumpkin, ginger, roselle or "sorrel", taro and dasheen.

Under conditions in Venezuela, pigeonpeas are grown in association with corn, with beans and with corn and beans together. A very strange association was observed by Escalante: pineapples and pigeonpeas[16/].

Italian millet, which is fast-growing, early-maturing, non-ratooning, has been found to be an excellent intercrop for the spreading medium-duration, slower-growing pigeonpea.

As forage, the pigeonpea has been combined with Rhodes grass and was better grazed than when combined with molasses grass in Hawaii (14). Pigeonpea combined with pangolagrass has given good results in Brazilian pastures (156). In mixed stands with elephant grass (Napier grass), pigeonpea declined after eight cuttings in less than two years and produced only 3,360 kg hay/ha (14).

In Rotations: In central India, in deep black soil, pigeonpea appears in rotated monsoon crop patterns as follows:

Sorghum + pigeonpea - fallow (2-year rotation)

Sorghum + pigeonpea - peanut (2-year rotation)

Sorghum + pigeonpea - cotton (2-year rotation)

Cotton - sorghum + pigeonpea - peanut (3-year rotation)

Improved cultivars maturing in 150-160 days are being recommended for rotation with wheat in northern and central India and with safflower in the south (144).

In the Bahama Islands, the pigeonpea is traditionally rotated annually with tomatoes. In Uganda, after one year of cotton, the field is devoted for 2 years to pigeonpea with finger millet interplanted in March-April and harvested in June-July. After the finger millet stubble is plowed under, sesame or sorghum takes its place. Either intercrop is ready to be harvested with pigeonpea from November to January.

In other Cropping Systems: Intensive row cropping of pigeonpea was made possible by the development of dwarf determinate varieties in Trinidad. Row cropping at high populations of 136,838 plants/ha as against 14,820 plants/ha in the traditional system, gives gross profits of $667/ha as against $412.50/ha (35).

INJURIOUS AFTEREFFECTS ON SUBSEQUENT CROPS

Pigeonpeas are reported among farmers in Puerto Rico to be hard on the land, the effect being particularly noticeable when some other crops are sown immediately after the harvest. This is not unique of pigeonpeas since other crops have been shown to have such deleterious effects on subsequent crops. Narayanan and Sheldrake (179), under conditions in India, observed that pigeonpea grown on the same soil in which pigeonpeas had been grown the previous year grew very poorly and their yields were reduced by about 80%. They attribute the situation probably to parasitic nematodes which do not form root-knots but which damage the roots of the plants; or to an allelopathic effect produced by chemicals released into the soil by the previous years pigeonpea crop or released by the decaying residues of this crop. Badillo and Lugo-López (43) observed, in a series of exploratory laboratory and greenhouse tests, that applying 11% of oven dried pigeonpea leaves on soils planted to beans depressed seeding germination and emergence more than sixfold. Canopy height and fresh weight of 25 day old bean plants were also adversely affected. A second test was conducted including 5 treatments: 0.69, 1.39, 2.78, 5.55, 8.32 and 11.00% of dried pigeonpea leaves. Germination, seedling emergence, plant height and fresh weight of tops and roots were reduced substantially with increasing levels of dried leaves. The injurious aftereffects were dramatic with only 6% germination at the 8.32% treatment (43).

Further tests were conducted using an extract of the leaves on solution cultures. The germination of beans, soybeans, cowpeas, corn and tomatoes was dramatically affected when the concentration of the pigeonpea leaf extract was increased to 4%. The germination of pigeonpeas remained unaffected at all concentrations. In a second test of the same nature pigeonpea leaf extracts were applied at concentrations ranging from 0 to 5.3%. In this case, beans were severely affected at levels as low as 0.8%; corn and tomatoes, at 3.2%; cowpeas, at 1.6% (43).

The deleterious effects of pigeonpea leaves and leaf extracts upon succeeding crops in a rotation were evident. The cause of such aftereffects remains to be determined. One possibility that merits further study is the inhibition attributable to hormones, mainly abcisic acid. The depletion of soil moisture and of available nitrates as a result of high sugar content of crop residues and roots have been postulated to produce similar aftereffects of sorghum on subsequent crops[17/]. The sugars furnish energy for the multiplication of microorganisms which compete with subsequent crops for available soil N. In the experiments with pigeonpea leaves and leaf extracts, the depletion of soil moisture is discarded since the growth medium used was either a solution or soil maintained at field capacity. It does not appear logical to attribute the aftereffects to N depletion since the pigeonpea fixes

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17/ Leonard, W.H., and Martin, J.H. 1963. Grain Sorghum, In "Cereal Crops", Chap. 21:679-721, MacMillan Publishing Co., Inc., N.Y.

sizeable amounts of atmospheric N for its own consumption and probably there are enough amounts left over for the use of subsequent crops.

HARVESTING

The pigeonpea is a labor-intensive crop. Labor may constitute 90% of the total cost of production. Also, peak labor periods may coincide with periods of heavy labor demand by crops such as sugarcane and tobacco (118).

The first picking of pods (as early as 7-1/2 weeks; more often about 6-9 months, or up to 12 months or more in late-maturing types (137,279), is done by hand in India, and pods are gathered regularly every 4 to 7 days. Frequent picking encourages podding. When the last are ready, the bushes are cut off close to the ground, and the tops are tied in bundles which are stood up in a covered shed to dry for several days.

Wherever the green peas are preferred for eating, all harvesting is done by hand (plucking the pods, or cutting off the top 15 or 20 cm of the plant with a small sickle or pruning knife) except for the final pods to ripen which are left on the bushes to dry for use as seed for planting the second or third year and which are threshed off after the bushes are cut back, although some farmers may depend on commercially available seed for replanting (118). Higher seed quality might result if seeds were picked as soon as mature to avoid penetration of the seed by fungi.

Some medium-season types will produce a second crop (as much as 40% of the total yield) after ratooning (69). Pruning above the height of the basal branches stimulates rapid regrowth (251). If the plants are kept for a second year, they are pruned back after harvest to encourage branching (312).

Because of increasing costs of manual labor, attention has been given to harvesting methods in Puerto Rico. It has been found that though higher yields are obtained by repeated pickings, it is more economical for farmers supplying canneries to harvest the entire crop at one time (242,245) early in the fruiting season when the majority of the peas are green and tender. Later, there is a progressively higher percentage of overripe peas and an undesirable lack of uniformity in the crop delivered to the factories (245).

In Puerto Rico, optimum dates for harvesting cultivar 2-B Bushy have been determined from the percentage of canning size pigeonpeas of samples drawn using samples from the standard time-yield curves or directly from tables prepared from them (45). The percentage of canning size pigeonpeas increased up to a maximum and then decreased. The canning quality of pigeonpeas harvested at the peak of the yield and at the peak of the production stages varied as the time interval at which they were produced varied. When the maximum yields (weight basis) came within a range of 18 to 26 days or within the range of 19 to 26 days (count basis) the canning quality was always either A or B grade. Beyond the upper limits of the above ranges only C or substandard grades were obtained. The time interval of 20.6 and 25.7 days corresponding to the peak points of the proposed harvesting curves lie within the above mentioned ranges, respectively. Yields beyond the 28th day were either a C or substandard grade. Harvesting at the maximum production stage may render a substantial produce which is not marketable. By harvesting at the peak points of the proposed harvesting curves good yields and a good quality produce will be obtained (45).

Lowland planting and mechanical harvesting are being investigated under conditions in Puerto Rico (3). In Trinidad, commercial interests are funding research in row planting and mechanical harvesting of dwarf strains (309). Green pods on plants 1 m high have been harvested by cutting the plants 0.3 m above ground with a reciprocating mower and then feeding the tops through a vining machine.

However, separation of pods is easier while they are still attached to the growing plant, and there is much need for improvement of harvesting machinery (27).

DRYING

Harvested pods may be sun-dried for 4-6 days, with frequent turning over to aerate and prevent spoilage by molds and with protection from rain and nighttime dew.

Oven-drying at 40-50°C requires 2 or 3 days. By either method, moisture should be reduced 10-12% and yields should not be calculated until such dehydration has been accomplished (27).

THRESHING AND WINNOWING

In India, the cut tops, after shed-drying, are shaken or flailed to detach the pods. Manual threshing is best done by placing the dried pods in a cloth sack and beating. Pods which fail to split must be opened by hand. Chaff and broken seeds are eliminated by winnowing.

In Guyana, a pre-harvest spray of Diquat (Diquat)--.44 g/110 l of water/ha--caused complete defoliation, exposing the pods and facilitating mechanical threshing (14).

COMBINED PRODUCTION OF FORAGE AND SEED

In Queensland, studies have been made to determine the feasibility of a single management system for grazing, forage and seed production. It is reported that the late-maturing types UQ1 and UQ38 can be cut to 90 cm height for forage purposes at 8-week intervals during summer-autumn. With a 12-week rest period in spring to allow for pod-setting, there is still a "reasonable" seed yield. A higher rate of plant survival and seed yield was obtained by permitting winter grazing of the more prolific UQ50 (13).

HUMAN FACTORS

In Trinidad, 81% of farmers, with 10-acre farms, grew less than 3 acres of pigeonpeas as an intercrop in 1964. They prefer to sell their crop direct to customers or to retail merchants to obtain a higher price than that guaranteed by the Central Marketing Agency and processors. Consequently, they are prone to limit production to quantities that can be readily disposed of at retail (36). Also, they are inclined to limit plantings to match available labor, especially free family labor (118). As in Puerto Rico and Guadeloupe, some early harvesting of green peas is done in late December to meet the traditional demand for this vegetable at Christmastime.

A considerable portion of the crop is retained for use at home, fresh, or dried and stored for use during the offseason. As much as 70% of a small farmer's crop may be reserved for home consumption and seed for next season's planting (118).

Therefore, certain cultivars preferred for use at home or popular on local markets will continue to be grown on a small scale, white types meeting commercial criteria will be planted on a large scale, especially for processing.

Educational efforts by extension workers will be needed to convert farmers from familiar varieties to improved types higher in yield and nutritional value; also to convince farmers of the value of inoculation and soil enrichment with P and sulphur, especially.

In India, farmers are replacing pigeonpea with high-yielding types of cereals, irrigated and fertilized, and pigeonpea culture is being moved to marginal lands. The aim of ICRISAT is to distribute improved strains of pigeonpeas suitable for various regions of India and more profitable for the farmer than the presently grown, low-yielding types which cannot compete economically with other crops.

POTENTIAL

As a multi-purpose bush legume, drought-resistant, of wide soil adaptability, somewhat salinity tolerant, requiring a minimum of fertilizer and producing high yields of edible seeds, rich in protein, which are popular as food in some areas of subtropics and tropics and increasing in value in international trade, the pigeonpea is worthy of promotion. Erect growth and non-shattering of seedpods are factors favoring mechanical harvesting, which is becoming more and more necessary in agriculture with spiralling costs of manual labor.

The variability of the plant and its product offer unlimited opportunities for breeders to develop and distribute superior types for home and commercial planting. Much progress has already been made and new research programs are being instituted in countries which have heretofore paid little attention to this crop.

LIMITATIONS

1. Slow early growth requiring weeding first 4-8 weeks.
2. Inefficiency of N-fixation by prevalent soil rhizobia.
3. Total transfer of nitrogen to plant, enriching soil only by shed leaves and flowers.
4. Susceptibility to frost.
5. Sensitivity to shade.
6. Susceptibility to wilt and rust diseases.
7. Susceptibility to seed-borne fungi decreasing seed quality.
8. Susceptibility to pod borers.
9. Late maturity of many types.
10. Labor intensive crop; continuous fruiting habit requiring repeated harvestings.
11. Indeterminate habit of many cultivars.
12. Low yield compared to cereal crops.
13. Difficult manual opening of immature pods.
14. Long cooking time of immature and mature seeds.
15. Deficiencies in amino acids.

16. Consumption and market limited to areas where the pigeonpea is already an accepted food (or to people from those areas who have migrated elsewhere).

17. As forage crop, short life (susceptibility to grazing damage and decline after multiple cuttings).

18. Total annual clearing of field to avoid carry-over of pests and diseases.

OVERCOMING LIMITATIONS

1. Use of pre-emergence herbicides. (Compare costs with alternative of plastic or paper mulch, apparently not yet applied to pigeonpea culture).

2. Matching of effective *Rhizobium* strains to pigeonpea cultivars to enhance nodulation and N fixation.

3. Determining appropriate fertilizer formula (low N, high P, moderate S, plus micronutrients) for maximum N fixation, good plant growth and high seed yield in low fertility soils.

4. Selection of early-maturing types and determining best planting date to avoid frost in subtropical areas.

5. Informing farmers of profitable intercropping systems and of yield reduction by unfavorable intercrops.

6. Selection of high yielding cultivars resistant to rust and wilt.

7. Timely harvesting of seed for planting to avoid fungus invasion of seed.

8. Development of cultivars resistant to pod borers (see LASIBA of Trinidad; thick-walled pod).

9. Selection and distribution of early-maturing types to shorten growing season and reduce per-day cost of production; also to permit two crops per year, except where

established dietary patterns demand interplanting of late-maturing pigeonpeas with tall, early-maturing intercrops.

10. Selection of cultivars with short-cropping season. Adoption of practice of harvesting at one time when majority of green pods are full (for processing plants). Develop better machinery for mechanical harvesting.

11. Development (for commercial plantings and mechanical harvesting) truly dwarf cultivars, not over 60 cm tall, with plant-to-plant variation not exceeding 15 cm , of determine habit (pods all at top of plant).

12. Selection and distribution of prolific cultivars capable of producing high yields at high density/ha. (Determination of maximum feasible density beyond which yield/ha declines). These cultivars should have large pods containing 6 or more seeds.

13. Development of simple devices for shelling immature pigeonpeas.

14. Selection of cultivars with good cooking quality. Adoption of hulling and flaking process to greatly reduce cooking time of mature, dry seeds.

15. Improvement of nutritional quality through breedings and fertilization.

16. Increasing production of fresh-frozen, shelled, immature pigeonpeas which should find ready acceptance in many markets where they are now totally unknown.

17. Continuation of breeding efforts (now in progress in Queensland, Australia) to develop hybrids of pigeonpea and related Atylosia grandiflora which may prove superior for forage and fodder. Consideration should be given to limitation of grazing and recovery of plant for subsequent seed production.

18. Chipping stalks for mulch (only if disease and pest control adequate).

An overall aim of current research programs is to develop cultivars which are daylength insensitive, of predictable height and dates of maturity when planted at all seasons, to permit pigeonpea production in all months of the year.

Early-maturing cultivars grown as annuals, can extend pigeonpea culture into marginal dry land and poor coastal soils unfavorable for other food crops.

Essential to coordination of pigeonpea improvement programs is the expansion of FAO's TAXIR system as a universal data bank of pigeonpea genotypes, varieties, strains, lines and cultivars; and of Rhizobium strains which nodulate the pigeonpea.

An ultimate goal should be widespread availability of inoculated, pelleted seed of named cultivars of known performance and suitability for various needs and situations, in order to assure the success of both the small farmer and the commercial producer of pigeonpeas and elevate this crop to the status it merits in the world food picture.

SUMMARY

Pigeonpeas are among the leading legume crops of the world and offer a vast potential as sources of high-quality protein for the tropics. They are presumably indigenous of tropical Africa where they have been cultivated for at least 2,500 years.

The pigeonpea ranks 5th in importance as a world crop among legumes after beans, peas, chick peas and broad beans. India produces 92% of the world's recorded crop of pigeonpeas; East Africa, 4%, Burma, 1 1/4%. In the Western Hemisphere, the Dominican Republic leads with 1 1/2 (29,000 mt annually). Haiti and Puerto Rico follow with about 5,000 mt each. Elsewhere in the Caribbean Region production is much lower and insufficient to meet domestic needs.

Its dietary importance has been widely recognized. It is rich in high-quality protein although deficient in methionine, cystine and tryptophane. It is low in antimetabolites and flatus-inducing sugars, and the testa is free of liposidase which can cause off-flavors.

Pigeonpeas are canned commercially in Kenya, Puerto Rico and Trinidad and Tobago. In canning factories, immature, pea-filled pods are steam-scalded for 90 seconds to inactivate the peroxidases, then the peas are mechanically shelled, processed and tinned in brine. Pigeonpeas are successfully canned and quick-frozen when midway between the tender and overripe stages. Enzyme inactivation is necessary to avoid undesirable changes in flavor, texture and appearance.

The growing plant is readily grazed by livestock. Lopped branches, pod husks (60% of the pod), leaves and broken seeds after the threshing, are fed fresh or dry to cattle, horses and other stock. In India, the seedcoats, "dust" and seed fragments from mills are prized as feed for dairy cows and are incorporated into commercial cattle feed mixtures. Seeds, seed meal, flowers and buds are fed to poultry and rabbits. The protein content of the plant is about equal to that of alfalfa; is higher in the early stages of flowering than in the advanced podding stage.

The pigeonpea is an erect, perennial or annual, bushy shrub to 6 m high with a vertical taproot that penetrates to 1 m or more and numerous rootlets, some bearing nodules with N-fixing bacteria. There is great variation in plant size, habit, photoperiodic behavior and seed characters. Most types flower when days are 11 to 11 1/2 hours in length, some are insensitive to daylength and will flower at any time of year. Usually flowering begins in 120-150 days and seed maturity occurs in 250-300 days from planting date, but flowering may occur as early as 60 days and seed maturity in 100 days in early types.

Genotypes and cultivars may be placed roughly in two main divisions: C. cajan var. bicolor D.C. (called arhar in India) includes primarily large, long-lived, late-maturing plants bearing red- or purple-stained flowers and hairy, purplish pods with 4 to 5 seeds usually purple-motted or dark-colored. C. cajan var. flavus DC. (called tur in India) includes mostly smaller, early-maturing plants, with all-yellow flowers and light-green pods with only 2 or 3 seeds. There are intermediate forms and crosses which display characters of both and do not fit into either division.

Some selected high-yielding cultivars from elite stocks are adapted to a wide range of climatic conditions, have unusually deep taproots, are resistant to drought and heat, are fairly insensitive to daylength between latitudes 10°N and 10° South, and bloom 65-90 days after planting.

At some locations, selections have been made from dwarf, small-seeded, early-fruiting types. Selections which are popular with small farmers are tall, indeterminate, day-length sensitive, late-maturing and large-seeded. Some have thick-walled pods resistant to pod borers. Others are soft-coated and "sweet" in the green stage. Semi-dwarf, determinate, daylength sensitive; have relatively short cropping season are suitable for planting late as row crops. In test plots, some of these selections have yielded 8,970-14,570 kg/ha of green pods.

The pigeonpea is sensitive to frost; is killed to the ground by a brief drop to -4.4° C; killed outright by several hours of 2.7° to 1.1° C. The plant grows and yields successfully in areas with a precipitation range of 500 to 1,500 mm per year.

Flower production and pod set are at the maximum during the first 3 weeks of the flowering phase. Pods developing from the earlier-formed flowers tend to inhibit development of pods from later flowers. Thus, the pigeonpea has the ability to continue to produce flowers and pods if earlier crops are damaged or lost, providing favorable rains occur.

The pigeonpea is noted for greater soil adaptability than other legumes. It prefers well-drained, deep, sandy loam but performs well in a wide range of soil types. The plant can endure soil salinity of 0.0005 g NaCl/g. It seems well adapted to a soil pH as low as 5 and as high as 8.

The primary pigeonpea disease in India is a wilt caused by the soil-borne fungus Fusarium oxysporum f. sp. udum (Butl.) which affects the entire plant in the reproductive stage. Sterility disease ("pigeonpea mosaic"), a virus infection carried by an Eriophyid mite (Aceria cajani), is widespread in India. Completely diseased branches fail to flower and nodulation is severely reduced. In Puerto Rico, yellow mosaic (Rhynchosia mosaic) is transmitted by whiteflies. It is a less serious problem than leaf rust, caused by Uromyces doilicholi Arth. or Uredo cajani, which may result in severe defoliation. Various stem rots, anthracnose and leaf spots, powdery mildew and witches'-broom disease occur at times in the West Indies, India and East Africa.

The pigeonpea is generally fairly resistant to rootknot nematodes. In Puerto Rico, a nematode (Rotylenchus sp.) has been found attacking nodules, causing stunting of the root system and above-ground parts.

Major insect pests of the pigeonpea are pod borers which are controlled by 2 applications of Endosulfan, 2.24 kg/ha, 2 weeks apart. Leaf-eating flea beetles are major pests in rainy seasons in Trinidad and Jamaica. Young plants may be injured by caterpillars, grasshoppers and cutworms. In northern Nigeria and Australia, stem base attack by termites has been prevented by dusting with Dieldrin. In Mauritius, six species of insects attack the flowers and pods and ten species feed on the leaves and young shoots. In Hawaii, the most serious enemy of the pigeonpea is the soft elongated flat scale (Coccus elongatus Sign).

In the pre-flowering stage, insects are seldom troublesome. After flower initiation, it may be necessary to spray an effective insecticide at least 2 to 4 times at 7- to 10-day intervals.

The pigeonpea is usually propagated by seeds which germinate well when fresh and may remain viable for several years. The field may be manually hoed, or plowed, disked and harrowed. Where there is danger of erosion, shallow tillage is recommended. If waterlogging is apt to occur during early stages of growth, the seeds should be sown on ridges.

When interplanted with other crops, pigeonpeas are usually 1 m apart with 1.5 m between rows, giving a density of 6,970 plants per hectare. Broadcast sowing is common when pigeonpea is grown as a solo crop, but many exposed seeds may be lost in dry weather. Row spacing facilitates cultivation and produces higher yields. Distance between plants in solid plantings may vary from 30 to 60 cm and between rows from 45 to 90 cm depending on the habit of the type grown, the fertility of the soil, and date of planting. When planted at an optimum depth of 5 cm (2-5 seeds/hole), 95% germination may be expected; a depth of 10 cm inhibits germination.

Close spacing ($0.25m^2$/plant) reduces plant yield but leads to high yields/ha--nearly 8,000 kg/ha from two harvesting of green pods. Dry matter as well as seed yield/ha decline at higher densities. In general, pigeonpeas should be planted 2.5 to 3 months before the end of the rainy season. Planting of short types is possible any month of the year, but the flowering of tall types occurs in periods of short daylength. Plant height may be controlled to a degree--early planting producing the tallest plants; late planting, the shortest.

For best development, thinning to one seedling/hill is essential at 4 to 9 weeks after planting. Transplanting seedlings for replacement should be done 4-7 days after emergence.

Initial growth is very slow and weed control is necessary during the first 4 to 8 weeks. Chemical weed control is more efficient than hand- or mechanical-weeding.

After the first 8-12 weeks of growth, the pigeonpea is remarkably drought-tolerant and can resist several months of dry weather. It will not tolerate excess water which causes seed decay and retards plant growth.

The pigeonpea is classed with the group of legumes which host the cowpea-type, alkali-producing rhizobia. Forty-five Rhizobium strains have been isolated from pigeonpea plants. Cultivars grown in the same soil differ in dominant Rhizobium strain-forming nodules. Indigenous rhizobia may be less effective than selected strains that can be introduced if methods can be found to replace established strains.

The pigeonpea plant takes up N continuously to maturity. Young plants are more effective in N fixation than older ones. The N level increases in the leaves up to flowerbud initiation and remains constant thereafter. In unfertilized pot-grown seedlings N fixation amounts 14.5 mg/plant/day. From 70 to 100% of the N can be transferred from the nodules to the rest of the plant soon after fixation.

Mo, S and Cu are essential to good nodulation and N fixation. Mo exerts a beneficial effect on elongation of roots and shoots, dry matter accumulation and free amino acid levels. S at 100 ppm in combination with low levels of N, P, K has significantly increased the methionine content and dry weight of pigeonpea plants and the number and dry weight of root nodules. If Cu is lacking or seriously deficient, there will be less N fixed even in the presence of effective strains of Rhizobium.

The pigeonpea is an exhaustive crop. Uptake of N and N-fixation increases by adding fertilizer P. Loss of N from the field in the first and second years is around 40 kg/ha and 80 kg in the third year.

Soil N could be replaced or enhanced only by incorporating shed leaves and flowers, which contribute 131 kg/ha of N, into the soil.

The pigeonpea is not ordinarily fertilized by growers. P is a critical factor in pigeonpea nutrition, increasing N uptake, yield of both dry matter and seeds, and enhancing protein content.

In N-deficient soils, application of up to 20 kg/ha N has increased yield, possibly because fertilizer N inhibits N-fixation by rhizobia.

Some experiments with pigeonpea in a sandy loam under irrigation have indicated that broadcasting of P is superior to deep placement. Under rainfed conditions, placement of N and P fertilizer at depths of 15 and 30 cm (half the quantity at each depth) gave higher yields than surface placement.

In a sandy loam of low fertility, grain and dry matter yields have increased progressively with applications of 33, 67 and 100 kg P_2O_5/ha. Application of 50-100 kg/ha of P increases the crude protein content of pigeonpea seeds. Deficiencies in P, Ca and Mg have a significant effect in depressing nodulation and plant growth.

If uninoculated and unfertilized, nodulation occurs within 10 days of germination and continues for 8 to 12 weeks. The majority of nodules is found in the first 30 cm of the root system, but are fairly common in the 120-150 cm zone. Nodule numbers progressively decline prior to plant maturity.

Seeds may be inoculated by watering a strain of Rhizobium (in peat or other carrier) into a furrow beneath the seed or by pouring a culture over the planted seed before covering with soil or the bacteria may be applied directly to the seed by a wet or dry method. To protect the rhizobia from acid fertilizer, or, at least temporarily, from certain unfavorable soil conditions, it is wise to pellet the inoculated seed--that is, to apply with an adhesive and then a coating of finely ground rock phosphate, lime, talc or powdered charcoal.

Legume seeds are commonly treated with fungicide in order to control seedling diseases, but fungicides are to some degree toxic to Rhizobium.

While the pigeonpea replaces and often adds N by shedding leaves and flowers, its deep taproot probably cycles nutrients other than N from deeper soil regions to the surface to the benefit of other crops.

In traditional intercropping systems, the pigeonpea is rarely sown with its companion crop in alternate rows. Often, one row of pigeonpeas is separated from the next by 4-10 rows of the intercrop. Late-maturing pigeonpeas are often planted together with sorghum, pearl millet, Italian millet or soybean. At Hyderabad, India, these intercrops, planted between pigeonpea rows 75 cm apart produced about double their normal yield as solo crops occupying the same area as the intercrops. Peanut interplanted with pigeonpea has shown a 9-15% reduction in yield. As a solo crop, yield of unshelled peanuts amounted to 1,991 kg/ha. Interplanted with pigeonpea, 1,965 kg/ha, but the pigeonpea has far offset the reduction by providing an additional 595 kg/ha of dry seeds. Maize (except dwarf maize), sorghum and pearl millet, as intercrops, provide too much shade for pigeonpea, reducing basal branching and yield.

As forage, pigeonpea has been successfully combined with Rhodes grass, pangolagrass and molasses grass. In mixed stands with elephant grass (Napier grass), pigeonpea declined after eight cuttings in less than two years and produced only 3,360 kg/ha hay.

In the Bahama Islands, the pigeonpea is traditionally rotated annually with tomatoes. In Uganda, after one year of cotton, the field is devoted for 2 years to pigeonpea with finger millet inter-planted in March-April and harvested in June-July. After the finger millet stubble is plowed under, sesame or sorghum takes its place.

Either intercrop is ready to be harvested with pigeonpea from November to January.

Intensive row cropping of pigeonpea was made possible by the development of dwarf determinate varieties. Row cropping at high populations of 136,838 plants/ha as against 14,820 plants/ha in the traditional system, gives gross profits of $667/ha as against $412.50/ha

In Puerto Rico, because of increasing costs of manual labor, it is more economical for farmers supplying canneries to harvest the entire crop at one time early in the fruiting season when the majority of the seeds are green and tender. Lowland planting and mechanical harvesting are being investigated. In Trinidad, research in row planting and mechanical harvesting of dwarf strains is underway. Green pods on plants 1 m high have been harvested by cutting the plants 0.3 m above the ground with a reciprocating mower and then feeding the tops through a vining machine.

Harvested pods may be sun-dried for 4-6 days with frequent turning; oven-drying at 40-50° C requires 2-3 days. Moisture should be reduced 10-12%. The dried tops are shaken or flailed to detach the pods which are then placed in cloth sacks and beaten to extract the seeds. Chaff is removed by winnowing. Chemical defoliation of the plants before harvest is a step that may be used to facilitate mechanical threshing.

Pigeonpeas appear to produce injurious aftereffects on subsequent crops in a rotation particularly if sown immediately after the pigeonpea harvest. The nature of these effects remains to be explained.

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APPENDIX

APPENDIX I

1. A. Nomenclature

1. Host legume

a. Common names: pigeon pea; Congo pea; Angola pea; goongo or gungo pea; Porto Rico pea; catjang pea; red gram, arhar, tur (India); coandu, cuandu, ervilha de Angola (Brazil); gandul, gandur (Cuba, Puerto Rico); guandu (Brazil, Panama); quinchoncho (Venezuela); guandul (Dominican Republic); wandoe (Surinam); wandu (Netherlands Antilles); pois Congo (Haiti); pois d'Angole (Guadeloupe); chícharo (Honduras); chícharo de árbol (Yucatán); chícharo de paloma (Colombia); cachito, frijol chino, frijol japonés (Guatemala); fri'ol de palo, alberga, alverja (El Salvador); abavante (Argentina); garbanzo falso (Nicaragua); timbolillo, quimbolillo (Costa Rica); puspo-poroto (Peru); kadios (Philippines); katjang goode (Java); lenteja Francesa (Guam); tua re (Thailand); ambrevade (Gabon).

b. Scientific names: *Cajanus cajan* Millsp., syns. *C. indicus* Spreng., *C. bicolor* DC., *C. flavus* DC., *C. luteus* Bello, *Cytisus cajan* L., *Cytisus pseudo-cajan* Jacq., *Cajan inodorum* Medic., *Cajan cajan* Britt.

2. Rhizobium

a. Common names: cowpea-type rhizobia; cowpea rhizobia; cowpea cross-inoculation group; or cowpea miscellany. Often referred to in general as nitrogen fixing-bacteria.

b. Scientific name: Rhizobium sp. Only six species of Rhizobium are now recognized. These species are delineated according to their ability to nodulate certain groups of leguminous plants. Such bacteria-plant groups have long been referred to as cross-inoculation groups.

The species of Rhizobium which inoculate tropical grain legumes such as pigeon pea, cowpea and mung bean are common soil inhabitants of the cowpea cross-inoculation group, for which organisms species designations are lacking. Because of this, it is traditional to refer to these organisms as rhizobia, or Rhizobium sp. Absence of species designation in the cowpea cross-inoculation group has sometimes led to confusion of cowpea rhizobia with Rhizobium japonicum, which nodulates and fixes nitrogen only in soybean, and also with Rhizobium phaseoli which nodulates and fixes nitrogen only in the common bean. Inoculants for soybean and the common bean will not cause nodulation in pigeon pea, cowpea, or mung bean.

APPENDIX II

Agricultural Chemicals for Pigeonpea Production

PESTICIDES

AZODRIN (MONOCROTOPHOS) phosphoric acid dimethyl ester with (E)-3-hydroxy-N-methylcrotonamide

BUX (BUFENCARB) 3-(1-methylbutyl)phenyl methylcarbamate + 3-(1-ethylpropyl) phenyl methylcarbamate (3:1)

CARBARYL 1-naphthyl-N-methylcarbamate

CYTROLANE (MEPHOSFOLAN) cyclic propylene P,P-diethyl phosphonodithio=imidocarbonate

DDT 2,2bis(p-chlorophenyl)1,1,1-trichloroethane

DIDIGAM (DDT with LINDANE or gamma BHC: see below)

DIELDRIN 1,2,3,4,10,10-hexachloro-6, 7-epoxy-1,4,4a,5,6,7,8,8a-octahydro-1, 4-endo, exo,-5,8-dimethanonaphthalene

DIPTEREX (TRICHLOROFON) 0,0-dimethyl,2,2,2-trichloro-1-hydroxyethyl phosphonate

DISULFOTON (BAY 19639; DITHIOSYSTOX; DI-SYSTON) 0,0-diethyl S- /2-(ethylthio)ethyl/ phosphorodithioate

ENDOSULFAN (THIODAN) 1,4,5,6,7,7-hexachloro-5-norbonene-2,3,-dimethanol cyclic sulfite

ETHYLENE DIBROMIDE sym-Dibromoethane;1,2-dibromoethane; ethylene bromide

FENSULFOTHION 0,0,diethyl 0-/(p-methylsulfinyl)phenyl/ Phosphorothioate

GAMMALIN (LINDANE or gamma BHC- see below)

GARDONA (STIROFOS; RABON) 2-chloro-1-(2,4,5-trichlorophenyl)vinyl demethyl phosphate

LINDANE (gamma BHC) 1,2,3,4,5,6-Hexachlorocyclohexane

MALATHION 0,0,-dimethyl S-(1,2-dicarbethoxyethyl)phosphorodithioate

METHYL BROMIDE bromomethane; monobromomethane; Embafume CH_3 Br.

PHOSPHINE	PH_3: mol. wt. 34.00. P 91.11%, H 8.89%
THIMET (PHORATE)	0,0-diethyl S-(methylthio-ethyl)phosphorodithioate

FUNGICIDES

BAVISTIN	2,Methyl-2-benzimidazole carbamate
BRASSICOL (TERRACLOR)	pentachloronitrobenzene (PCNB)
DEMOSAN (CHLORONEB)	1,4-dichloro-2, 5-dimethoxybenzene
TERRACOAT L205	pentachloronitrobenzene + 5-ethoxy-3-trichlormethyl-1, 2,4,thiadiazole
THIRAM 50	tetramethyl(-thiuram-disulfide) OR Bis(dimethylthiocarbamoyl) disulfide

GROWTH REGULATORS

ETHEPHON	2-(chloroethyl phosphonic acid)
TIBA	2,3,5-triidobenzoic acid

HERBICIDES

DACTHAL	(chlorthal dimethyl)-dimethyl tetrachloroterephthalate
DIQUAT	6,7-dihydrodipyrido/1,2-a:2´,1´-c/ pyrazidiinium dibromide
GESAPRIM 80 (ATRAZINE)	2-chloro-4-ethylamino 6-isoproprryl amino 5 triazine
NITROFEN (TOK)	2,4-dichlorophenyl 4-nitrophenyl ether
PARAQUAT (GRAMAXONE)	1,1´-dimethyl-4,4´-bipyridynium cation
PROMETRYNE (CAPAROL)	2,4-Bis(isopropylamino-6-methylthio)-S-triazine
TREFLAN (TRIFLURALIN)	a,a,a-Trifluoro-2,6-dinitro, N,N-dipropyl-p-toluidine

APPENDIX III

Scientific Names of Other Plants Referred to in this Study

Alfalfa	_Medicago sativa_ L.
Bamboo grass, or bull grass	_Paspalum fasciculatum_ Willd.
Banana	_Musa_ spp.
Bean	_Phaseolus_ spp.
Black gram, or urd	_Vigna mungo_ Hepper (_Phaseolus mungo_ L.)
Broad bean	_Vicia faba_ L.
Butterfly pea	_Centrosema_ spp.
Cassava, or yuca	_Manihot esculenta_ Crantz
Chickpea, or garbanzo	_Cicer arietinum_ L.
Coconut	_Cocos nucifera_ L.
Cocoyam, yautía, tanier or malanga	_Xanthosoma_ spp.
Cotton	_Gossypium_ spp.
Cowpea	_Vigna sinensis_ Endl. (_V. unguiculata_ Walp.)
Elephant grass or Napier grass	_Pennisetum purpureum_ Schumach.
Finger millet	_Eleusine corocana_ Gaertn.
Garlic	_Allium sativum_ L.
Ginger	_Zingiber officinale_ L.
Hyacinth bean	_Dolichos lablab_
Italian millet	_Setaria italica_ Beauv.
Koa haole, lead tree or ipil-ipil	_Leucaena leucocephala_ De Wit
Maize	_Zea mays_ L.
Molasses grass	_Melinis minutiflora_ Beauv.
Mung bean	_Vigna radiata_ R. Wilcz. (_Phaseolus aureus_ Roxb.)
Okra	_Abelmoschus esculentus_ Moench (_Hibiscus esculentus_ L.)

Onion	*Allium cepa* L.
Pangola grass	*Digitaria decumbens* Stent
Pea	*Pisum sativum* L.
Peanut, or groundnut	*Arachis hypogeae* L.
Pearl, or Indian millet	*Pennisetum americanum* K. Schum.
Pepper, chili	*Capsicum* spp.
Pepper, green	*Capsicum annuum* L.
Pineapple	*Ananas comosus* Merr. (*A. sativus* Schult.)
Potato	*Solanum tuberosum* L.
Pumpkin	*Cucurbita* spp.
Rhodes grass	*Chloris gayana* Kunth.
Rice	*Oryza sativa* L.
Roselle	*Hibiscus sabdariffa* L.
Sesame	*Sesamum indicum* L.
Sorghum	*Sorghum bicolor* Moench (*S. vulgare* Pers.)
Soybean	*Glycine max* Merr.
Stylo	*Stylosanthes* spp.
Taro and dasheen	*Colocasia esculenta* Schott
Tobacco	*Nicotiana tabacum* L.
Tomato	*Lycopersicon lycopersicum* Karst. ex Farw. (*L. esculentum* Mill.)
Vanilla	*Vanilla planifolia* Andr. (*V. fragrans* Ames)
Velvet bean	*Mucuna deeringiana* Merr.

APPENDIX IV

Institutions with pigeon pea programs

1. Research programs:

INDIA:

International Crops Research Institute for the Semi-arid Tropics (ICRISAT), Begumpet, Hyderabad. Established in 1972.
(exploration; documentation; collection and classification of the pigeon pea and chickpea germplasm of the world; 5,530 pigeon pea entries; breeding of superior varieties of pigeon pea; back-crossing modified bulk hybrid method; selection for photo-insensitivity; systems of cultivation; pollination; induction of mutations; intergeneric hybridization; cooperative international breeding; nutritional value studies).

Indian Agricultural Research Institute (IARI), Regional Research Station, Rajendranagar, Hyderabad. (hybridization)

All-India Coordinated Research Project on Pulses, Indian Council for Agricultural Research and Co-operating Agencies, New Delhi.
(coordinated trials on pulses)

Agricultural College and Research Institute, Coimbatore
(insecticides for pigeon pea)

Tamil Nadu Agricultural University, Coimbatore
(hybridization)

Assam Agricultural University, Department of Zoology and Entomology
(insect pests of pigeon pea)

Govind Ballabh Pant University of Agriculture and Technology, Pantnagar, U.P.
(collection, screening, evaluation and maintenance of pigeon pea germplasm and evolution of new varieties; breeding for extra early and medium varieties suitable for multiple cropping and rotation, also for disease resistance)

Regional Agricultural Research Institute, Gwalior
(yield components of pigeon pea)

	Ranchi Agricultural College, Department of Plant Breeding, Ranchi, Bihar (selection and hybridization)
	Punjab Agricultural University, Department of Plant Breeding, Ludhiana, Punjab (genetic variability; breeding; physiological analysis of yield; plant protection)
SRI LANKA:	A. R. S., Maha Illuppallama (genetic variability; physiological analysis of yield)
MALAYSIA:	Rice Research Institute of Malaysia (RRIM), Sungei Buloh (evaluation of 21 strains as cover crop, green manure, fodder and seed crop)
PHILIPPINES:	Economic Gardens, Los Banos, Laguna (breeding; production agronomy)
REPUBLIC OF CHINA:	Asian Vegetable Research and Development Center (AVRDC), Shanhua, Taiwan
JAPAN:	Faculty of Agriculture, Kochi University, Kochi (production agronomy; morphology)
AUSTRALIA:	Queensland Department of Primary Industries, Brisbane (1941-64: comparison of pigeon pea with other legumes; 1964: grazing trials; 1966-67: comparison of pigeon pea with other legumes from the standpoint of forage and seed production, found inferior to hyacinth bean. 1972: classification of 95 accessions at Redland Bay, southeastern Queensland).
	University of Queensland, St. Lucia (began evaluation of pigeon pea as a dry-season forage crop in 1969. Interest has now swung to potential as a grain crop, especially for export to the Middle East where Saudi Arabians have learned of the pigeon pea from Indian and Pakistani residents. Research includes growth analysis; response to sowing date; effects of density on seed and dry matter yield; effects of defoliation; animal production trials (grazing; chicken feeding); ongoing studies include genotype X environment interaction; mechanical harvesting; preemergent weedicides; maturation of seeds and pods. Cooperating with ICRISAT, IITA, and University of the West Indies, Trinidad).

Commonwealth Scientific and Industrial Research Organization (CSIRO), Division of Tropical Crops and Pastures, St. Lucia and Brisbane
(nitrogen fixation; potential areas of production; present cultivars succeed only in humid tropical coastal and subcoastal areas where land is limited)

Department of Agriculture, South Perth, Western Australia
(breeding)

University of Sydney, Sydney
(inoculants)

HAWAII:

University of Hawaii, Agricultural Experiment Station, Honolulu
University of Hawaii, Department of Agronomy and Soil Science
(Nitrogen Fixation by Tropical Agricultural Legumes (NIFTAL) Project)

AFRICA:

Nigeria

International Grain Legume Information Centre, International Institute of Tropical Agriculture (IITA), Ibadan

Uganda

Makerere University Farm, Kampala
(Cajanus improvement program initiated in 1968. World Collection of 5,526 lines grown for evaluation; 718 selections in breeding program supported by the Rockefeller Foundation; hundreds of crosses made with a view to developing short-duration, high-yielding, leafspot-resistant cultivars; yield and fertilizer trials; investigations of fodder potential and grain quality)

Kenya

University of Nairobi, Department of Crop Science, Nairobi
(Pigeon Pea Project --research initiated by J. F. Moses Onim in 197[illegible]. Aim is to provide growers with higher-yielding, more pest-resistant and disease-resistant varieties, under dry conditions. A collection of 607 cultivars has been assembled--236 Kenya types, others from Makerere Pigeon Pea Programme, ICRISAT, IITA, the Sudan, and University of the West Indies, Trinidad. Studies include transpiration rates (greenhouse and field); root growth rates; radical growth in germinating seeds; drought-resistance; outcrossing; selection and agronomic studies; field screening for drought-resistance and high seed yield; protein and amino acid assays. Recently funds for intensifying

research have been provided by the International Development Research Centre, Ottawa, Canada. Joint research experiments have begun with the Departments of Food Science and Technology and Animal Production to establish biological values of promising cultivars in the breeding program.

PUERTO RICO: University of Puerto Rico, College of Agricultural Sciences, Mayaguez
(nitrogen fixation; fertilizer requirements; planting dates and density; cultural practices; breeding program; genetic studies (cross-pollination, inheritance factors, variety/environment reactions); protein studies; seed quality; diseases and pests; processing (canning and freezing))

DOMINICAN REPUBLIC: Instituto Interamericano de Ciencias Agrícolas (IICA), Santo Domingo

JAMAICA: University of the West Indies, Mona
(growth regulators)

Ministry of Agriculture, Crop Research Division, Hope Gardens, Mona
(trials of new determinate, dwarf types bred and selected for mechanical harvest, obtained from University of the West Indies, Trinidad)

TRINIDAD AND TOBAGO: University of the West Indies, Department of Biological Sciences, St. Augustine, Trinidad
(Grain Legume Programme. In 1967, the Rockefeller Foundation provided grants for research on grain legume and root crops. Has 305-acre farm, laboratory and greenhouse; germplasm collection. Studies of pigeon pea include continuation of germplasm collection begun by H. J. Gooding in 1956; also microbiology, microclimatology, effects of soil moisture; crop physiology; agronomy; crop protection; mechanical harvesting; breeding; problems affecting yield and nutritional quality. Research in breeding and nitrogen fixation is now sponsored by British Overseas Development Ministry (ODM).

GUADELOUPE: Centre de Recherches Agronomiques des Antilles, I.N.R.A., Station de Amelioration des Plantes, Petit-Bourg, and Station de Genetique et de Amelioration des Plantes, Versailles.
(200 accessions from India, Africa and West Indies. Studies include germination, growth rate,

morphological variability, agronomy, insect-resistance, soil adaptability; selection of cultivars especially to aid agricultural development on the island of Marie-Galante).

VENEZUELA: Cátedra de Cereales y Leguminosas, Facultad de Agronomía, Universidad Central de Venezuela, Maracay, Estado de Aragua

GUYANA: Central Agricultural Station, Mon Repos.

MEXICO: Centro de Investigaciones Agrícolas de la Península de Yucatán (CIAPY), Mérida
(pigeon pea and other legume experimental plots at Campo Uxmal; Ing. Pedro Villanueva P., Jefe de Campo Uxmal)

EL SALVADOR: Instituto Interamericano de Ciencias Agrícolas (IICA), San Salvador
(germplasm collection)

COSTA RICA: Centro Agronómico Tropical de Investigación y Enseñanza (CATIE), Turrialba
(genetic variability; breeding; germplasm collection; production agronomy)

PANAMA: Ministerio de Agricultura, Comercio y Industrias, Panamá
(legume research program--25% devoted to pigeon pea; three cultivars released; some interest in development of commercial canning of green seeds).

University of Panamá, Panamá City

ENGLAND: Rothamsted Experiment Station, Harpenden, Herts
(greenhouse experiments; nitrogen fixation)

USA: United States Department of Agriculture, Agricultural Research Service, Beltsville, Maryland
(Germplasm Resources Laboratory; working collection of 282 pigeon pea accessions; 4,000 accessions from India; 3,280 from Iran, per Feb. 1973 Inventory)

University of Florida, Institute of Food and Agricultural Sciences (IFAS), Agronomy Department, Gainesville (Prof. G. M. Prine)

University of Florida, Institute of Food and Agricultural Sciences (IFAS), Agricultural Research and Education Center, Homestead (Dr. Herbert H. Bryan)
(trial plots of pigeon pea accessions; includes 100 lines received from ICRISAT; 6 from IITA;

studying potential for grain and/or forage production in northern Florida: Aim is to develop low-growing, early-maturing, high-yielding pigeon pea, averaging over 4 large seeds per pod)

Texas A & M University, Soil and Crop Science Department, College Station, Texas (Dr. Eli L. Whitely).
(experimental plots of pigeon pea accessions)

2. Extension programs:

TRINIDAD AND TOBAGO: University of the West Indies, Department of Biological Sciences, St. Augustine, Trinidad
(Grain Legume Programme; advisory bulletin "A New Approach to Pigeon Pea Production", for farmers)

APPENDIX V

Principal sources for seed, inoculant and Rhizobium Cultures (for research purposes)

SEED:

International Crops Research Institute for the Semi-arid Tropics (ICRISAT), Hyderabad, India (including 5 types found to be male-sterile or with low pollen fertility)

International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria

INOCULANT:

Bactogin Laboratories, Jalapur; India
Bio-Fertilizers, Bangalore, India
Indian Agricultural Research Institute (IARI), Division of Microbiology, Delhi, India
Barfe Laboratories, Bombay, India
G. B. Pant University of Agriculture and Technology, Haldi, India (Pantnagar Culture)
CSIRO, Cunningham Laboratory, St. Lucia, Queensland, Australia
CSIRO, Davies Laboratory, Townsville, Queensland, Australia
Laboratorios Dispert S. A., Montevideo, Uruguay
Instituto de Pesquisas Agronomicas (IPAGRO), Secretaria de Agricultura, Porto Alegre, Brazil
Central Agricultural Station, Mon Repos, Guyana (to fill the nitrogen needs of local farmers, for legume production, Guyana has begun an inoculant production system).
Nitragin Company, Milwaukee, Wisconsin, USA

RHIZOBIUM CULTURES:

Indian Agricultural Research Institute (IARI), (Division of Microbiology, Delhi, India
Centro Internacional de Agricultura Tropical (CIAT), Cali, Colombia
University of Hawaii, Niftal Project, Honolulu (identifying superior Rhizobium strains, matching them to legumes; determining effective management systems)
USDA, Agricultural Research Service, Beltsville, Maryland (World Rhizobium Culture and Collection Center)

APPENDIX VI

Identification of crop producing areas and yields

1. Individual countries:

	Year	Estimated area hectares	Dry seed yield kg/ha	Estimated total yield metric tons
INDIA (92% of world's recorded crop)	1975	2,540,000	716	1,818,000 (FAO)
AFRICA (4% of world's recorded crop)				
Northern Uganda	1975	99,000	406	40,000 (FAO)
Kenya	1968			5,471
	1976	60,000	500 (est.)	30,000 (16)
Malawi	1975	35,000	570	20,000 (FAO)
Tanzania	1975	20,000	500	10,000 (FAO)
Nigeria -	Fairly important crop, in scattered stands, mainly semi-arid and sub-humid regions; sometimes humid; no statistics (74)			
BURMA	1975	68,000	351	24,000 (FAO)
BANGLADESH	1975	3,000	724 (FAO)	2,172
PAKISTAN (southern)	1975	1,000	623 (FAO)	623
DOMINICAN REPUBLIC	1975	13,000	2194	29,000 (FAO)
HAITI	1975	7,000	538	4,000 (FAO)
PUERTO RICO	1975-1975			4,087 (1)
	1975	6,000	742	4,452 (FAO)
PANAMA	1975	2,000	749 (FAO)	1,500
VENEZUELA	1975	1,715	473	4,011 (Min. of Agr.)
TRINIDAD AND TOBAGO	1975	1,194	1667 (FAO)	1,984

JAMAICA	1973	2,024	600	1,766
	1974			1,722
	1975			2,145
	1976			1,371 (Min. of Agr.)
BAHAMAS	1952			101.5
	1965			159
	subsequently declined; no current statistics			

2. <u>International scale</u>:

WORLD production of pigeon peas in 1975 was estimated at 1,976,217 metric tons, placing this crop 5th in importance among legumes after beans, peas, chickpeas and broad beans. Plantings are being increased in established growing areas and the pigeon pea is being introduced as a new crop in other regions because of current widespread interest in legumes as protein sources and enrichers of soil.

APPENDIX VII

Composition, 100 g. edible portion of pigeonpeas

	Water	Food energy	Protein	Fat	Carbohydrate Total	Carbohydrate Fiber	Ash	Calcium	Phosphorus	Iron	Vitamin A value	Thiamine	Riboflavin	Niacin value	Ascorbic acid
	%	Cal							Mg		I,U,			Mg	
Pigeon peas, Immature seeds	70.3	114	7.0	.6	29.8	3.3	1.3	32	122	1.5	70	.37	.18	2.3	43
Dry seeds, husked	13.1	333	21.9	1.6	59.9	1.5	3.5	92	282	4.5	140	.47	.18	2.0	5

Source: Woot-Tsuen Wu Leung, R.K. Pecot and B.K, Watt, Composition of Foods Used in Far Eastern Countries, Agriculture Handbook No. 34. U.S. Department of Agriculture, Washington, D.C. 1952.

APPENDIX VIII

Methionine and sulphur content of varieties of red gram

Variety	Methionine (mg/g)	Sulphur (mg/g)
P.2780	3.00	1.30
P.3758	2.40	2.50
P.4768	2.20	2.90
P.4415	2.60	1.90
P.4657	2.30	1.72
R.24	2.05	1.92
S.32	2.05	1.32
S.34	2.03	1.72
Commercial varieties		
T.21	1.33	1.52
C.11	1.80	1.70
N.84	1.55	1.50
T-15-15	1.60	1.50

Source: L.M. Jeswani, VARIETAL IMPROVEMENT OF SEED LEGUMES IN INDIA, pp. 9-18, in: N.W. Pirie (editor), Food Protein Sources. International Biological Programme 4. Cambridge University Press, Cambridge. 1975. Reproduced with permission.