BIBLIOGRAPHIC DATA SHEET

1. CONTROL NUMBER	PN-AAH-492
2. SUBJECT CLASSIFICATION (695)	AF00-0130-0000

3. TITLE AND SUBTITLE (240)
The eleusines; a review of the world literature

4. PERSONAL AUTHORS (100)
Rachie, K. O.; Peters, L. V.

5. CORPORATE AUTHORS (101)
Int. Crops Research Institute for the Semi-Arid Tropics

6. DOCUMENT DATE (110)	7. NUMBER OF PAGES (120)	8. ARC NUMBER (170)
1977	187p.	633.171.R119 a

9. REFERENCE ORGANIZATION (130)
ICRISAT

10. SUPPLEMENTARY NOTES (500)

11. ABSTRACT (950)

12. DESCRIPTORS (920)

Millet	Semiarid land
Africa	South Asia
Grain crops	Crop diseases and pests
Plant protection	Plant breeding
Nutritive value	Reviews

13. PROJECT NUMBER (150)
931097200

14. CONTRACT NO.(140)
AID/ ta-G-1421

15. CONTRACT TYPE (140)

16. TYPE OF DOCUMENT (160)

AID 590-7 (10-79)

THE ELEUSINES

(A Review of the World Literature)

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and
LeRoy V. Peters

INTERNATIONAL CROPS RESEARCH
INSTITUTE
FOR THE SEMI-ARID TROPICS
(ICRISAT)

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FOREWORD

While the Eleusines are practically unknown outside of Asia and Africa, they have had a definite place in the planning and research of the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), since it started operations in July 1972. ICRISAT's interest in this crop, principally *Eleusine coracana* Gaertn. or finger millet, is likely to continue for two reasons:

First, finger millet plays an important part in the nutrition of millions of people in the semi-arid tropics, particularly in India and East Africa. Secondly, it is one of the hardiest crops grown in this region and will undoubtedly have an intricate role in farming systems developed by ICRISAT and other research institutions for a large part of the semi-arid tropics.

In this publication, Dr. K. O. Rachie and Dr. L. V. Peters have provided information of incalculable value to researchers and agriculturists at many levels. Their cogent and thorough review of the world literature is certain to make this publication a desk-top reference for the increasing number of scientists working on third-world cereals.

Making this information available to all who have need of it is part of ICRISAT's mission as a world center with a major responsibility for developing improved farming systems for the semi-arid tropics. We are gratified that we can make a contribution to the flow of information about and understanding of the Eleusines and proud to be listed as publisher of this timely work.

Dr. R. W. Cummings, director
International Crops Research Institute for the
Semi-Arid Tropics – ICRISAT
Hyderabad, India. 1977.

THE ELEUSINES
(A Review of the World Literature)

KENNETH O. RACHIE[1]
AND
LEROY V. PETERS[2]

GENERAL AND HISTORICAL

Importance

Ragi, or finger millet (*Eleusine coracana* Gaertn.)—also known in English as birdsfoot, coracana, and African millet; in India as nagli; in Ethiopia as dagussa; and in East Africa in Swahili as wimbe—is cultivated for human food in Africa and southern Asia. Among the millets of the world, ragi ranks fourth after the Pennisetums, or pearl millet; foxtail millet, *Setaria italica*, and *Panicum miliaceum* or proso millet. It is estimated to comprise approximately 8% of the area and 11% of the production of all millets in the world. Perhaps 4½ million metric tons of grain are produced annually on as much as five million hectares throughout the world; almost the entire production is confined to Africa and to Asia. India alone produces between 40 and 45% of the total world production, and most of the rest of ragi millet is produced in Central Africa. In India, the states of Karnataka, Tamil Nadu, and Andhra Pradesh produce most of the ragi crop. Karnataka and Tamil Nadu produce about 61% of the total crop. The southeastern area of Karnataka adjoining regions of Tamil Nadu and Andhra Pradesh produce the bulk of the Indian crop. However, ragi is also grown, to a more limited extent, along the Western Ghats of southwest India and in the foothills of the Himalayas; in fact, some production extends along the hills of southern Asia as far east as China.

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In Africa, ragi is produced principally in East Africa and in the countries surrounding Lake Victoria, that is, Uganda, Tanzania, Rwanda, Burundi, Eastern Zaire, Keaya, and to a lesser extent, Ethiopia, Sudan and Somaliland. It is also grown farther south, in Rhodesia and Madagascar. In Central and West Africa, it is grown to a limited extent in Centrafique, southern Chad and northeastern Nigeria. In India, ragi ranks second after pearl millet, producing about half of the total annual production of that crop and equalling all other minor millets combined. In East Africa, ragi is by far the most important cereal crop in Uganda, equalling the acreage and production of all other cereals combined. It is really the only other millet of consequence after Pennisetums throughout Africa (Leonard and Martin, 1963; Rachie, 1975).

Adaptation and Use

Ragi is little known outside of India, southern Asia, and Africa except for its wild relative *Eleusine indica*, otherwise known as goose-grass, which has become, in many parts of Europe and the United States, a grassy weed. Ragi is one of the hardiest crops grown under the dry cultivation conditions in its regions of adaptation. It is grown in areas with usually 500 to 1,000 mm (20 to 40 in.) of rain. It is often associated with rice on lands where irrigation is not feasible, or as an off-season crop in rotation with that cereal. Typically, it is grown on rather steep or sloping lands, often in mountainous foothills or similar areas; it is found at elevations up to about 2,400 m (about 8,000 ft.). This crop also has a wide range of seasonal adaptation, and can be grown in any part of the year if moisture is adequate and temperatures are above a minimum level. Thus, it is grown not only as a dryland crop in the rainy season, but also it is very successful as an irrigated crop in the dry season.

Ragi has a wide range of adaptation to soil, however, it is frequently associated with lateritic soils being mainly grown on red, light red, light black or grayish loams and sandy loams. In some areas it may be cultivated on well-drained alluvial soil as well; it is reputed to tolerate a certain degree of alkalinity in the soil.

Rain-fed ragi is often rotated with sorghum, other millets, pulses and grams, oilseed crops, and peanuts or mixtures of them. It may also be grown as a short-season crop before or following the main rice crop or vegetable such as chillies, sweet potatoes, onions, eggplant and other garden crops. Sometimes it is mixed with pulses like *Dolichos lablab* and pigeonpeas, or foxtail millet, sesame, sorghums and pearl millet.

Ragi grain is used in many forms for human food. It is most frequently ground to make flour and prepared in the form of porridge, unleavened bread or cakes, which may be cooked, baked or fried with condiments, spices and other foodstuffs. The green grain can be roasted and eaten as a kind of vegetable. Another favorite preparation is parching the mature grain, then grinding and mixing with some other food such as crude sugar, salt, spices, or buttermilk. Ragi is one of the few crops from which excellent malt can be prepared, and it is much appreciated for this characteristic. As such, the malt can be used directly, or in the preparation of various beverages and drinks (ICAR, 1961).

The other qualities of ragi are not so well-known, but are also important. In some areas, such as in southern Karnataka, the fodder is highly valued for feeding cattle and other ruminants, and it makes a good supplement to the income from the grain.

Aside from its uses as a cereal grain and/or fodder, ragi is often grown because of its high reproducibility ranging between 200 and 500 fold. Thus a little seed goes a long way in reproducing the crop. A second very valuable attribute of this cereal is its grain-keeping quality. The grain is very highly resistant to storage insect pests, even without any special care or attention. It is reputed to remain in good condition even when stored as long as fifty years (Ayyangar, 1932).

Historical

The genus Eleusine is comprised of ten annual or perennial grasses. These commonly occur in the warmer regions of the Old World, particularly in southern Asia and Africa. However, one species, *E. indica*, has wide distribution in Europe and also in the New World. The term Eleusine is derived from Eleusis, an old epic city sacred to Demeter, the Greek deity presiding over agriculture. Nearby is the Rharian plain where the goddess is reputed to have sown her seeds of wheat and taught agriculture, its arts and sciences to the people. The term coracana is derived from Kurukkan, the Singhali name for this grain. It is technically a tetraploid and its near common relative in the wild state is *Eleusine indica*, a diploid.

Early writers separated out the different forms of ragi and identified them differently. Those with finely striated grains were first called *E. tocussa*; whereas those with curved spikes were called *E. coracana*, and plants with straight spikes as *E. stricta*. Later Hooker (1897) brought them all under *Eleusine coracana* Gaertn., which he considered to be the cultivated form of *E. indica*. Early botanists (DeCandolle, 1886; Watt, 1908), and some later geneticists (Narayanaswami, 1952; Mann, 1946, 1950) suggest a probable Indian origin of this millet. The earlier authors mention that the ancient monuments of Egypt bear no trace of its cultivation in earlier times; and early Graeco-Roman authors, who knew the country did not refer to it. In India, ragi is mentioned by Sanskrit writers and referred to as ragi or rajika. The grain is mentioned in the Bower manuscript dating to the Eighth Century (Watt, L.C.). Burkhill (1935) suggested that *E. coracana* is a cultigene of the wild species *E. indica* (L.) Gaertn., and that its early selection by man appears to have taken place in India since (a) it has been cultivated for a very long time there; (b) it has a Sanskrit name, ragi; (c) it was probably in India when the Aryans reached there; and (d) its decrease in Africa from east to west suggests its introduction from the East. Werth (1937) was of the opinion *E. coracana* originated in India from where it spread through Arabia, Abyssinia and to the rest of Africa. Mann (1946, 1950) suggested that owing to the widespread cultivation and importance of ragi in India, it most probably developed there.

Other botanists, particularly in recent times, have favored the African origin theory or believe that the crop originated both in Africa and in India. Vavilov (1951) proposed that ragi originated in Abyssinia; while Chandola (1959) expressed the opinion that perhaps ragi developed simultaneously both in Africa and in India. It was pointed out that representatives of the genus Eleusine have several features in common, especially in respect to similar dominant genes; a similar number of wild species; and similar diversity of species and their cytological behavior. However, Anderson (1960) has recently called attention to the fact that there is the possibility of much earlier movement of primitive agriculture products from Africa through Yemen and the seaward edge of the Arabian peninsula and into southern India. The lack of earlier realization of this possibility is attributed to the fact that these crops bear Sanskrit names and that these millets are of minor importance and had escaped earlier attention.

Winton and Winton (1932) have pointed out the importance of ragi in Central Africa to the writers and explorers who mention it in the early part of the century. They refer specifically to a man named Mitlacher (1901) who states that ragi ranked with sorghum as a staple cereal in Central Africa and that it was grown in German East Africa (Tanganyika) under the name of 'wimbi'. They also refer to its cultivation in Japan and Southern China as well as in India, and the Sunda Islands. Other early writers quoted by the Wintons include V. Dalla Torre (1905) and the Rev. Fred. R. Bunker (1900's) who spent thirty years in Rhodesia and neighboring provinces. They considered ragi a chief food of the African natives in Central East Africa and refer to the Kaffir name 'Luku', and also mention that it has long been a common bread cereal of Amandau people of Mozambique, being known as 'upoko' or 'umngoza'. They declared that this millet yields a bread of excellent flavor, notwithstanding statements that it has somewhat bitter taste.

In more recent times, taxonomists and geneticists using more advanced techniques have studied the species Eleusine and its wild relatives. Kennedy-O'Byrne (1957) and Mehra (1962–63) studied the broad range of diversity in East Africa and a wild tetraploid form, *Eleusine africana*. From these evidences they suggest the origin of *Eleusine coracana* in Ethiopia, or further south, and its later transport to India in pre-Aryan times.

TRADITIONAL PRODUCING REGIONS

The regions of the world where ragi is most intensively grown are namely two—these are the regions immediately surrounding Lake Victoria in East Africa and southern India in the southeastern part of Karnataka and the adjoining districts of Tamil Nadu and Andhra Pradesh. These relatively small and circumscribed regions account for nearly three-fourths of the world's production of this cereal. Nevertheless, ragi is grown to a more limited extent over a much broader area than these two regions.

Africa

Although the most important regions of ragi cultivation in Africa are in Uganda in the vicinity of Lake Victoria and Lake Kyoga, and between Lake Tanganyika and Lake Victoria, there are other areas of cultivation in the western, eastern and southern part of the continent. There are also limited areas in the Central African Republic, southern Chad, northeastern Nigeria, northern and eastern Zaire, the Sudan, Ethiopia, Somaliland, Uganda, Kenya, Rwanda, Burundi, Tanganyika, Malawi, Zambia, Rhodesia, Mozambique and Madagascar (Johnson and Raymond, 1964).

India

Southeast and central Karnataka, and the adjoining districts in Tamil Nadu and Andhra Pradesh produce three-fourths of India's ragi crop. The most important districts of Karnataka include Bangalore where over 60% of the cultivated area is sown to the millet, Kolar where almost 50% of the cultivated land is under ragi, and Tumkur and Hassan where about 40% of the cropped area is in millet. In these areas the annual rainfall varies from 20 to 40 in. (500 to 1,000 mm), the temperatures range from 26.7 to 32.2 C. (80 to 90 F); and the typical soil is an easily-worked, light veranous, deep red loam (Iyengar, 1945–46).

The important growing districts of Tamil Nadu include Salem, Coimbatore, North Arcot, Ramanathapuram, Chingleput and South Arcot, and Visakhapatnam, Chittoor, Anantapur and Nellore, in Andhra Pradesh (Madras-DA, 1954). Ragi is also grown in the lower to intermediate elevations of the Himalayas. It is occasionally grown on plains or hilly regions of other states including Gujarat, West Bengal, Bihar, Uttar Pradesh, Himachal Pradesh and Kashmir. Ragi is also grown along the foothills of the mountainous ranges in the east from India through Burma, Thailand and on across southern Asia. By and large these regions are relatively remote and not easily accessible; therefore, statistics on production are skimpy. It is also cultivated to a limited extent in Malaysia and in Sri Lanka (formerly Ceylon) under conditions similar to those prevailing in southern India. It appears probable that ragi was introduced into Malaysia along with the Indian workers in plantations during the past two or three centuries.

China and Japan

Ragi millet is reported to be grown to a limited extent in both

Japan and China. In China it occurs mainly in Shantung, Shensi, and Szechwan. In these regions it is used most often in making beer for which it is particularly prized (Anderson, 1948).

THE PLANT

Taxonomy

Synonyms and Vernacular Names

The most common vernacular names for ragi include: Finger, Birdsfoot, African, or Ragi Millet (in English); Ragi, Nagli, Mandua, or Kurukkan (India); Dagussa or Wimbe (East Africa); and Mil Rouge or Coracan (French). Of these, the term Ragi is, perhaps, the most universal and widely used. A more complete listing of vernacular names is given in Appendix 1 (Iyengar, 1945 46; Adrian and Jaquot, 1964).

The most widely accepted scientific name for this crop is *Eleusine coracana* Gaertn. Others include: *Cynosurus coracanus* Linn.; *Eleusine cerealis* Salisb.; *E. spherosperma* Stokes; *E. stricta* Roxb.; and *E. tocussa*, Fresen. The most closely-related wild species, from which it is apparently derived, include the diploid, *E. indica* (2n = 18), and the wild-intermediate tetraploid, *E. africana* (Kennedy-O'Byrne, 1957).

Botanical Descriptions

The genus Eleusine is a member of the tribe Chlorideae. The Eleusines have been described by Hitchcock (1950), Mansfield (1952), and Bor (1960). Hitchcock described Eleusine Gaertn. as follows: Spikelets few to several-flowered, compressed, sessile, and closely imbricate in two rows along one side of a rather broad rachis, not prolonged beyond the spikelets; rachilla disarticulating above the glumes and between the florets; glumes unequal, rather broad, acute, one-nerved, shorter than the first lemma; lemmas acute, with three strong green nerves close together, forming a keel, the uppermost somewhat reduced; seed dark brown, roughened by fine ridges, loosely enclosed in the thin pericarp. Annuals with two to several rather stout spikes, digitate at the summit of the culms, sometimes with one or two a short distance below, rarely with a single spike.

Type species *Eleusine coracana*, the name comes from Eleusis, the town where Demeter was worshipped. Bor (L.C.) provides a key to the species of Eleusine; this is as follows:

1. Annuals — basal sheaths glabrous at base:
    2. Spikes, slender narrow (5 mm wide), straight, nearly glabrous at the base; seeds oblong, obtusely trigonous — *E. indica*.
    2. Spikes stout, broad (about 1 cm wide), incurved, hairy at the base; seeds globose — *E. coracana*.
1. Perennials — stem creeping and rooting at the nodes, glaucous; basal sheaths wooly at the base — *E. compressa*.

There are good descriptions of these species (*Eleusine coracana*, Gaertn.) by Seva O. Botnis, including Ayyangar (1932), Hector (1936), Porteres (1951), Leonard and Martin (1963). Of these, Hector (L.C.) has given the most straightforward description which reads as follows:

Stems. These are erect or slightly kneed, compressed and glabrous. The leaves are numerous distichous; the sheaths compressed, open, striate, glabrous, and with more or less ciliate margins; the ligules are short membranous and fimbriate; the blades are linear and tapering to an acute point, folded and striate, glabrous except at the often ciliate margins.

Inflorescence. —The inflorescence is a terminal umbel of 2–10 straight thick sessile spikes 3–5 in. long, usually with 1 to 2 (rarely more) additional spikes 1/4 to 3 in. below each rachis, is angular, pubescent villous at the base, but glabrous above.

Spikelets. —The spikelets are often curved, crowded, 2–10 flowered. The lower glume is ovate, obtuse and keeled with lateral nerve close to the keel. The upper glume is similar, but slightly longer. All flowers are perfect except the terminal which may be only seminate or infertile. The lemmas are broadly ovate, acute and three-nerved. The paleas are somewhat shorter than the lemmas, two-keeled with the keel wings. There are two lodicules, broad and trunky; three stamens; an obovate ovary with distinct style and plumose stigma. The grain is oblong, reddish brown with finely curved striate, and falls at maturity.

Eleusine indica, the wild relative of *E. coracana*, commonly referred to as goosegrass, has been described by three botanists, including Montelucci (1942), Porteres (1951), and Hitchcock (1950). Hitchcock (L.C.) describes it as branching at the base, ascending to prostrate, very smooth; culms compressed, usually less than 50 cm long, but sometimes as much as 1 m in length; blades flat or folded, 3 8 mm wide; spikes mostly two to six, rarely more, or but 1 in depauperate plants, flat 4 to 15 cm long. *Eleusine africana* is a new semi-wild species described by Kennedy-O'Byrne, it is distinguished from *E. indica* by its more robust habit, larger flower parts and tetraploid chromosome number. Specifically it has a wider rachis, larger spikelets, broadly winged on the lower keel and has a much longer lemma than *E. indica*. It occurs as a weedy contaminant in fields of cultivated cereals in East Africa. Kennedy-O'Byrne (L.C.) suggests *E. africana* to have been the progenitor of one form of *E. coracana*. He believes it may have originated by chromosome doubling from *E. indica* and that the cultivated ragi was developed by human selection of large grain mutants from *E. africana*. In fact he proposes that two different forms of *E. coracana* have been evolved, one of which has been derived by selection of large grain mutants in *E. africana* for use as food and which subsequently was cultivated as one of these forms. In the second case, he proposes another form of *E. coracana* was evolved as a selection from naturally doubled *E. indica*. In proof of this theory, the evidence that a wide range of intermediate types, which are obviously hybrids, between *E. africana* and *E. coracana* occur naturally in cultivated fields of cereals in East Africa. He further states that *E. africana* is restricted to northeastern Africa and has not been involved in any evolution of the ragi cultivated in Asia, since the wild tetraploid has never been found in Asia.

Herbarium specimens at Kew were studied by Mehra (1962 63) using the metroglyph analyses devised by Anderson to evaluate the variation pattern amongst the different specimens. Using this technique four distinct types were proposed based on cytological and morphological policies, these include:

Wild types:

1. *Eleusine indica*: 2n = 18 chromosomes; it has a smaller plant; narrow rachis; thin stems, relatively short glumes and lemma, and spikelets; shattering spikelets, small seeds are enclosed in glumes and thin racemes.
2. *E. africana*: 2n = 36 chromosomes; it has a larger plant but generally similar to *E. indica*; has wider rachis, thicker stems and longer spikelets, glumes, and lemmas; the spikelets shatter and it has shattering seeds as well.

Cultivated types: 1. *E. coracana* (African-highland type): 2n = 36 chromosomes; longer lemmas, glumes, and spikelets; spikelets are non-shattering and it has plump grains; the seeds are enclosed inside the glumes.

2. *E. coracana* (Afro-Asiatic type): 2n = 36 chromosomes; it has shorter glumes, lemmas and spikelets; has non-shattering spikelets and plump seed; and seeds thresh free from the glumes.

Cytological studies were conducted amongst these types and revealed regular pairing and formation of eighteen bivalents during meiosis in the sporocytes (micro sporocytes) in *E. coracana* and *E. africana*. Regular bivalent formation during meiosis, the presence of duplicate factors and polymeric factors suggest *E.coracana* to be an allotetraploid. The cultivated and wild types at the tetraploid level cross readily with each other producing a variety of hybrid types. Mehra (L.C.) further describes the eco-geographic adaptation of the two types of *E.coracana*. He states the Afro-Asiatic type of *E. coracana* grows in drier areas below 4,000 ft. and its distribution in Africa extends from Ethiopia and the Sudan to Kenya, Uganda and Tanzania. Variance with either short or long glumes occur in this type. The African highland type of *E.coracana* is also present in the same areas, but in damp sites above 4,000 ft. with an extended distribution south through Malawi, Rhodesia, and into the Union of South Africa. It is distinguished by having long glumes controlled by G-1, G-2, and G-3 factors, one of which in the dominant condition gives short glumes; any two give medium glumes; and all three produce long glumes.

As a result of his findings, Mehra (1963) suggests a working hypothesis on the origin of cultivated *Eleusine coracana* (L.) Gaertn. forms based on both cytotaxonomic and morphological analyses. *E.indica* (2n = 18 crossed with an unknown species of Eleusine also 2n = 18 chromosomes) produced a wild hybrid, a diploid which doubled its chromosomes and produced a wild tetraploid with 2n = 36 chromosomes. This evolved into *E.africana*, also a tetraploid, from which was selected *E.coracana* with 2n = 36. The stage between *E.africana* and *E.coracara* is characterized by repeated hybridization and continuing introgression of the two types and was known as the African highland type. Other genotypes may have evolved from this

African highland type in possessing the glume inhibitory mechanism, thereby becoming the Afro-Asiatic type. Alternatively, this second Afro-Asiatic type may have evolved directly from *E. indica* by another Eleusine species. It appears highly likely that selection by man has played an important role in the final evolutionary stages of either cultivated types. A botanical comparison of these three types as given by Kennedy-O'Byrne (1957) and Porteres (1951) which contrasts *Eleusine indica* with *Eleusine africana* and *Eleusine indica* with *Eleusine coracana* are presented in Appendices 2, 3 and 4.

E. reniformis, a new species of ragi, was described and studied by Divakaran (1959b, 1962) at Coimbatore in Tamil Nadu. This strain of ragi was designated as E. C. 4626 and was compared with a standard strain Co. 3 (E.C. 593). These comparisons involved measurements of the grain size, thickness of the peduncle and length of the glumes and weight of earhead and grain. Vegetative characters were also recorded in the field during plant development. The investigator reported that the normal *E. coracana*, or globular ragi is readily distinguishable from the reniform ragi from the seed to the mature plant stages. Globular ragi has ovate-spherical grains, the first leaf is long and narrow and is inserted or borne at an angle of more than 45 degrees to the culm. The mature plant has an elegant appearance on account of its long flowing leaves. Reniform ragi has kidney-shaped grains. The first leaf is short and broad and parallel to the ground. The plant is vigorous and grows rapidly in the early stages of development, but the mature plant appears wilted owing to the presence of a large number of drooping or bent leaves. It has very poor tillering, indiscriminate lodging and lacks uniformity in grain size, characters that have rendered this type uneconomic for commercial use.

Classifying the Cultivated Species

There have been attempts to categorize the cultivated species of *E. coracana* based primarily on the head types and their opening and lengths of the fingers. Ayyangar *et al.* (1932) has described the earhead of ragi as a terminal whorl consisting of digitate spikes radiating from the apex of the culm with an almost constant single spike a little lower down, probably indicative of a second whorl. The terminal spikes are commonly referred to as 'fingers' and a lower single spike as the 'thumb'. Each of these spikes consists of two rows of sessile spikelets alternatively attached to the underside of a flattened rachis. The florets are distichously arranged in the spikelets.

There are three readily recognized head shapes in ragi: (1) Top-curved, (2) In-curved, and (3) Opens. The In-curved have short fingers of about 4 to 7 cm in length, curve in and practically close up the central hollow giving the earhead an obovate shape. The Top-curves have intermediate fingers 5–10 cm in length, and tend to curve in at the tips only, thereby retaining the central hollow. The Opens have the longest fingers averaging 8–15 cm, gape out, and present the characteristic funnel-shaped appearance; which on drying tend to curve out slightly.

The number of spikelets in a finger vary somewhat, tending to be greater in the main season than in the summer season. There is relatively little difference in number of spikelets among the three earhead shapes, although Top-curved tend to have slightly more spikelets than the other two types as shown below from 200 readings in four seasons, or an overall average of 67:

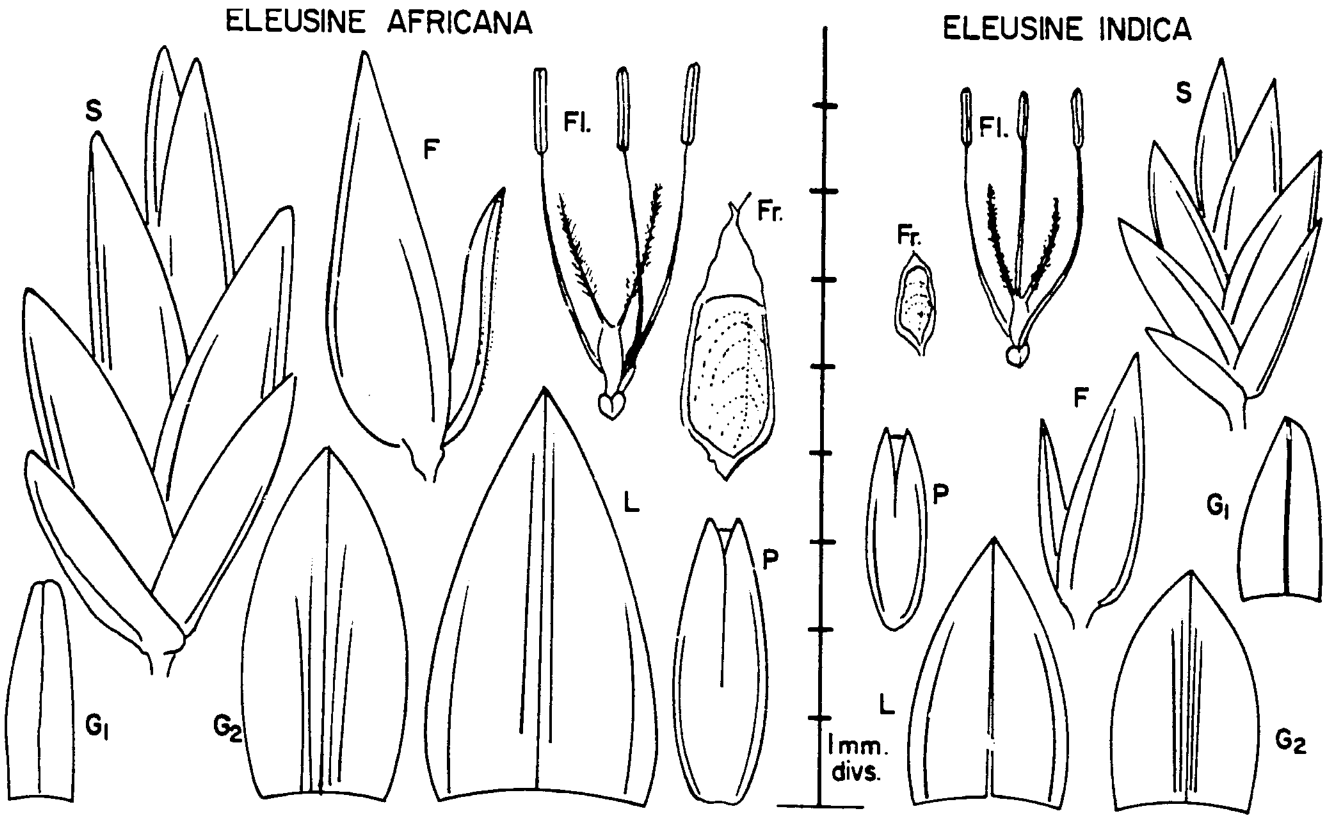
Spikelets per finger

Season	*Top-curved*	*In-curved*	*Opens*
Main Season	73	72	67
Summer Season	66	63	59

In all three groups the spikelets increase in density towards the top. The average density of spikelets per centimeter length of the whole finger was 9.5 for Top-curved, 11.8 for In-curved, and 6.7 for Opens. The corresponding averages for the upper halves of the earhead were: Top-curved = 11.4, In-curved = 12.9 and Opens = 7.9.

Morphology—Anatomy

There are relatively few works on morphology and anatomy of *E. coracana*, or its wild relatives. Perhaps the most comprehensive of these are studies made by Porteres (1951). He outlined and described all the major organs and tissues of the ragi plant. Other authorities have studied specific parts during different growth stages of this species. Noda and Hayashi (1959) studied the coleorhiza of several cereals, including maize, sorghum, pearl millet, proso, foxtail millet, barnyard millet, ragi and Job's tears. Weber (1938) described the morphogenesis of the earhead and related development of the vegetative shoot to that of the inflorescence in detailed studies of



Details of spikelets of *E. africana* and *E. indica*: S, spikelet; G1, lower glume; G2, upper glume; F, floret; L, lemma; P, palea; Fl, flower; Fr, fruit. All dissections X 12. (Redrawn from Kennedy-O'Byrne, 1957).

E.coracana and its relative *E.tristachya*. Iyengar (1961) covered some of the aspects of intraseasonal growth-variation in different plants. He compared the reproductive parts, specifically the flowering axis of *E.coracana* with *E.egyptica*, rice, sorghum, cotton and other crops. Narayanaswami (1955) described the structure and development of the caryopsis of several Indian millets in a series of papers. He traced the embryogeny and distribution of the vascular supply in detail in *E.coracana*. Naresh (1963) compared the embryology and the fruit development of the two wild species *E.indica* and *Dactyloctenium aegyptium*, both of the tribe Eragrosteae, sub-family Pooideae. He observed several considerable parallelisms in these two species as described below:

Microsporogenesis is of the successive type and results in isobilateral tetrads of microspores. The microspores round up and the generative cell is cut off which later gives rise to two male cells which are spindle-shaped. Pollen grain at the time of shedding is three-celled and has a smooth exine with a single pore. The tube nucleus begins to degenerate while still in the pollen grain. The ovule is semi-anatropous, bitegmic, and tenuinucellate. A single hypodermal archesporial cell differentiates in a nucellus which behaves directly as the megaspore mother cell. It undergoes meiosis to form a linear, or T-shaped tetrad of megaspores. The chalazal megaspore is functional in the development of embryo sac and conforms to the Polygonum type. The antipodals become very large and divide in the *D.aegyptium* while in *E.indica* the primary number of three is retained. Both occupy a lateral position in the ovule. Double fertilization takes place. Further development of the caryopsis follows closely that of other grasses.

The spikelets of *E.africana* and *E.indica* were compared by Kennedy-O'Byrne, and these are shown in the figure on page 14.

Porteres (1951) has prepared a series of morphological and histological illustrations of leaf and stem structures to facilitate studies of the vascular and support systems of these organs.

Phylogenetic Relations

The plant *Eleusine coracana* is described by Porteres (L.C.) as a thermophyte of intermediate photoperiodism with a phase of photosensitive transition and belonging to a group of plants which have been named nyctohereroperiodic to distinguish them from the hemeroperiodic and the nyctoperiodic, respectively 'long-day plants' and 'short-day plants'.

Floral Biology

The inflorescence of ragi has been described by Coleman (1920) and Ayyangar (1932) as a terminal whorl bearing 2 to 10, but averaging 5 or 6 spikes arranged like a birdsfoot at the top of the peduncle. The lowest spike is separated by 2 to 5 cm from the other spikes and which arise from the same point at the end of the stem. This lower spike appears to be a thumb, or a bird's first claw; it is commonly referred to as the thumb, and the other spikes as the fingers. In each finger there are about 70 spikelets, each spikelet having five to seven complete flowers. In the spikelet the flowering proceeds from bottom to top and in a finger the order of flowering is from the top spikelet downward. An earhead contains 1,500 to 3,000 flowers, and the flowering period varies from six or seven to ten days, the largest number opening on the third day after flowering commences.

The initiation of flowering and emergence of earhead were studied by Porteres (1947). He reported on the interrelations of temperature and photoperiod in the flowering of *E.coracana* and *Brachiaria deflexa*. These plants were studied in their habitat where they flower under a photoperiod of 11 hrs and 30 min, to 11 hrs and 50 min, and are exposed to mean daily temperatures of 26° to 30°C. Experimental plants from seedings exposed after July 13 to photoperiods of 8, 10, 12, 14 and 16 hrs were dissected and studied macroscopically and microscopically in the development of their stem spikes. The optimum photoperiods for *E. coracana* were found to be 11 hrs and 30 min, and for Brachiaria, 11 hrs and 40 min. Older plants, however, were more sensitive to photoperiod than the young ones. The interaction of plant age or development with photoperiod was explained in terms of the growth phase concept. Essentially, a minimum threshold temperature is required for the completion of the thermophase and is regarded as dependent on the excess of daily mean temperatures above the threshold temperature.

Anthesis and pollination in *E.coracana* has been studied and described by several authors, including Ayyangar (1932), Ayyangar and Wariar (1934), Chavan *et al.* (1955), Chavan and Shendge (1957) and Coleman *et al.* (1921). Ayyangar and his associates found the complete emergence of the inflorescence requires about 10 days and flowering extends over at least 7 or 8 days. Ragi types with curved panicles undergo anthesis between 2 and 5 a.m., while panicles with open spikes tend to flower between 1 and 3 a.m. The general tendency of the flowers is to open and progress from the top to the bottom in a finger. In a spikelet, however, the order is reversed and proceeds from the bottom to the top, and from the bigger to the smaller flower. The stigma remains receptive for a very short period after its emergence from the glumes. The period of anthesis in the flower is very short and is conducive to self-pollination, but occasionally cross-pollination occurs.

Chavan and associates studied the flowering habits of ragi, specifically the medium late strain E-31 in north Konkan region and at the Agricultural Research Station at Karjat. They found flowering to be at its maximum at 8 a.m. when the humidity is at its highest, between 95 and 99%, and when the minimum and maximum temperatures are 70° to 74°F and 76° to 87°F, respectively. Flowering continued there up until 10 a.m. and the anthers were found to be dehiscing and shed their pollen about 45 min after first emerging. They observed blooming to synchronize on all the fingers of an ear and found the major portion of the blooming is completed within two or three days.

Ragi pollen was germinated artificially on moist filter paper under glass by Coleman *et al.* (1921). They observed that large quantities of pollen were obtained when ragi flowers with several peduncles were immersed in water and kept overnight. Ample pollen was obtained the next day in the morning between 7 and 9 a.m. when the anthers were kept moist, but they readily burst when allowed to dry. They found that rainy days, early mornings, with heavy dews or artificially maintained high humidities effectively prevented pollen dehiscence.

The flower of ragi is very small and extremely difficult to manipulate; in fact, some form of magnification is essential in order to emasculate the tiny floret. The fact that anther dehiscence is prevented by high humidity offers a possible alternative to the conventional method of emasculation followed by pollination or use of the hot water method, which is probably more commonly used. This would involve maintaining a high humidity in the immediate vicinity of the florets by keeping a moist chamber around the plant or by bagging the head in a light wet wrapper covered with a plastic bag.

These high humidity conditions could be maintained until all the heads had exserted their anthers and these could be wiped off with a solution of water and possibly a detergent following which the desired pollen could be introduced for fertilization purposes.

Physiology

The physiology investigations reported concerning ragi are very limited and concern predominately studies in the germination of seeds. These include seed treatments of various kinds including the application of certain phytohormonal treatments to seeds and to growing plants; investigations on water relationships and drought-resistance; and a very limited experiment on nutrient uptake.

Germination of seeds.—Studies were carried out on germination of seeds following immersion for several months to establish whether ragi seeds would persist in the soil under flooded conditions, and then commence growing when conditions were more favorable. Narasimhamurthy (1949) collected seeds from a late ragi variety and sowed them in pots immersed with water for a period of 4½ months. He then permitted the pots to dry down and resowed these seeds in larger pots with similar soil under ideal conditions for germination. After four days of drying the pots were watered and germination of the emerging seedlings were counted. These ranged from 25 to 61%, averaging approximately 44.3% for the six replicates. In another experiment, the immersed seeds were removed and sun-dried until they became quite hard. They were then germinated under ideal conditions and the percentage of germination was found to be from 79 to 84%. This was considered as proof that ragi seeds retained their viability under paddy land conditions for at least four months. Thus, it is not safe to grow a ragi crop intended for seed purposes in a field previously cropped with an early ragi.

The effect of various temperatures on the seed germination of some tropical plants was studied by Knapp (1966). Germination of eleven species was tested at different temperatures between 8° and 48°C. For most species optimum germination was reached at 24° and 32°C in three days. *Eleusine coracana* germinated in excess of 80% at temperatures ranging between 8° and 22°C, while *Pennisetum typhoides* and *Sorghum vulgare* did so at 16° to 40°C, however, none of these species germinated at 48°C. Ragi is considered to have some tolerance of salt and alkalinity. In an experiment conducted by Mehrotra and Gangwar (1964), the cultivar T36–P was germinated on salty and alkaline soils ranging from low salinity to low alkalinity to high salinity (E.C. 4.3 × 10^{13})/high alkali (90% exchangeable Na); but it did not survive as well as maize and *P. mungo.* It was concluded that this variety did not have as high tolerance of alkalinity-salinity as the other two species.

An experiment to improve the rate and germination in rye was carried out at Bangalore by Dawson (1965). Seeds of finger millet were soaked in half their weight of distilled water for 24 hrs and gradually dried in the shade at 27°C for three days before sowing in pots and in the field. Compared with untreated controls, plants from treated seeds emerged a full day earlier, were bigger, and a deeper greer, and possessed more tillers and a more extensive root system. Ear length, 1,000 grain weight and grain yield per plant were all increased by this treatment. Yields were increased by 40% over the control. It would seem apparent that soaking seeds in this way would favor their rapid and early germination and possibly give the plants an advantage in a particular climatic situation or where later development is more highly susceptible to variance of moisture limitations or buildups of endemic pests.

Phytohormonal treatments.—There have been a number of experiments designed to treat ragi seeds with growth hormones and other substances to make them grow faster and possibly enhance their agronomic characteristics and yields. Vijayaraghavan and Narayanan (1947) report the results of pre-soaking pearl millet and ragi seeds in growth hormones such as indolylacetic acid and also in different dilutions of urine from pregnant cows. In the case of ragi, pre-soaking the seeds for 24 hrs in 10% and 1% urine solutions gave, in one pot-culture experiment, increases of 78% and 86% more grain, and 155% and 128% increases in straw weight respectively. In a field experiment, increases in grain yield of 20% were achieved by this urine soaking treatment. Moreover, flowering was hastened by about a week. However, pre-soaking in indolylacetic acid did not show any increase in yield. Similar, but much smaller, increases were obtained by soaking of pearl millet in urine. These are rather interesting results and suggest continued investigations in order to confirm whether there is indeed any beneficial effect of such soaking treatments.

Other experiments in treating seed with β-naphthoxyacetic acid and applying foliage sprays of the same material were reported by Pillai *et al.* (1958). He found these treatments increase growth and yield of ragi grain and, within the limits observed, he found the effects were proportional to the concentration used. Similar experiments were continued by Narayanan and Menon (1960). They pre-soaked seeds of ragi with IAA and NAA at concentrations of 50 parts per million. They did not obtain any differences in plant heights, number of tillers, or in time of flowering, but grain yields were increased by 2.5 to 5%. However, NAA applied before flowering as a foliar spray at 20 parts per million had an adverse effect on grain yield. Non-significant increases in straw yield (2.8 to 21.7%) were observed when growth substances were used for soaking seeds or as foliar sprays. These treatments were also tried on rice, but the results were not consistent.

The effects of maleic hydrazide applied at low rates ($<$ 0.25 lb/acre) six weeks after sowing was found to increase the yields of grain and straw from ragi in experiments reported by Naidu and Murty (1961). However, the same rate of maleic hydrazide applied four weeks after sowing was observed to suppress apical growth and the flowering of ragi. In other experiments, gibberellic acid solutions at 25, 50 and 75 parts per million were sprayed on ragi 15 and 30 days after transplanting. The optimum internode elongation occurred at 50 ppm solution. Flowering was early, but the heads were malformed. The average weight increase in grain per head over the control was 35.4% in these studies (Appalanaidu *et al.*, 1961).

Seedcoat inhibitor.—The presence of a seedcoat inhibitor was reported in ragi by Sastry and Dawson (1966). Water-leached seeds of three different ragi varieties were collected and used for germination studies. These leachates were decolorized by activated charcoal and were observed to inhibit both coleoptile and seminal root growth.

Effects of X-raying seeds.—The effect of treating seeds with X-rays was studied by Krishnaswamy and Ayyangar (1941). They reported that plants grown from X-rayed seeds had long, thin and wiry roots that developed at almost every node, down along the stem to the leaf sheath base, where they encircled the stems.

Fast neutron seed treatment.—Four dosage rates of fast neutron treatment revealed no immediate male-sterility in studies in Uganda by Peters, Odelle and Atadan (1971). However, early plant vigor, total plant growth and height were greatly reduced with increased treatment rate.

Heat hardening of tissues.—Heat hardening experiments conducted in Russia were reported by Aleksandrov and Fel'dman (1958). They found that heat hardening lowered the sensitivity of epidermal cells in *P.miliaceum* and *E.coracana*. Work on other crops had earlier shown that heat hardened tissues were more resistant to several injurious factors, such as alcohol, alkalinity and high hydrostatic pressures.

Water relationships.—Earliest records of experiments on transpiration rates in field crops including ragi are reported by Leather (1910). He showed that ragi was among the most efficient of the six species tried in terms of production of dry matter per unit of water used. In this experiment 250 units of water were required for each unit of dry matter produced for ragi. The next most efficient crops in this comparison were *Paspalum scrobiculatum*, which required 300 units, maize, which required 330 units, and sorghum, which required 400 units. The unmanured treatments sometimes required somewhat more water per unit of dried matter produced. This was true for maize, but not for sorghum and the two millets included in the comparison.

The comparative leaf anatomy of eight millets was studied by Krishnaswamy and Ayyangar (1942). They found that all of these species, including sorghums, possessed a number of zeric and non-zeric features intermixed, and that it was not necessarily possible to interpret the water efficiency use or drought resistance from a study of the comparative anatomy. They found *E.coracana* and *P.miliaceum* also had large club-shaped plastids arranged on the inner wall of the cell, and bunched together at their narrower ends; in other species the plastids were small, oval and arranged on the outer wall. In comparing the different species, they observed that sorghum showed the least number of zeric features, but this species was able to withstand drought better than all the others. On the other hand, *E.italica* had the most zeric features in respect to leaf surface, but showed the least zeric motor tissue. The authors suggest that the several zeric features exhibited are probably ancestral and may help in the selection of drought-resistant forms. The drought resistance, however, is mainly dependent on the growth form and manner of resistance. They also concluded that the anatomy of the leaf of *E. coracana* justifies its inclusion in the Sacchariferae of Avduluv.

The leaf structure of the ragi plant was also studied in relation to drought resistance. The leaves of the ragi plants cultivated in soils of varying drought—65, 47, 40 and 36.5% moisture—were subjected to a series of hydration and dehydration. In all four cases the hydration and dehydration isotherms and the hysteresis were nearly coincident. These suggest that the cavities and the open pores in the leaves are nearly of the same size. Among six plants studied, ragi was 'ed superior to balsam and paddy in drought resistance, but not tolerant compared with wheat and oats (Rao *et al.*, 1949).

Nut. :ent uptake.—Investigations on the uptake of major nutrients were reported by Venkataramana and Rao (1961). They found that potassium was taken up by the straw, but that straw yields were not proportional to the uptake of this element. They also recorded that grain yields of ragi responded to phosphorous and straw yields responded to nitrogen. Nutrient uptake in dry matter production was also studied at Anand by Khatri and Mehta (1962). They found dry matter increased continuously up to harvest time and maximum production took place between the milk and dough stage of the grain. Nitrogen, however, was accumulated uniformly during all growth stages up to the dough stage, after which its demand decreased rapidly. The maximum accumulation of phosphorous occurred between the pre-flowering and milk stage; whereas for calcium it occurred between milk and dough stages; and for magnesium, between the dough and harvest stage; while potassium was absorbed almost uniformly from the young to the dough stage. However, at all stages of growth, the percent of potassium was greater in the stem than in other plant parts, while that of calcium and magnesium was higher in the leaf and root than in other parts. The grain was richer in nitrogen than the other nutrients. The amounts of nutrients removed by the ragi crop producing three tons of dry matter per acre were: nitrogen = 51 lb; phosphoric acid = 58 lb; potassium = 154 lb; calcium = 52 lb; magnesium = 20 lb. The highest total cation concentration was in the leaf, while for any plant part the

K-ion concentration was greater than that of Ca- or Mg-ions at a corresponding stage of development. The cationic ratio (Ca + Mg)/K was lowest for the stem and highest for the leaf and root.

Culture of excised roots.—Experiments carried out by Padmasini (1947) with excised roots growing in a basal medium of sucrose and inorganic salt showed that ragi roots can synthesize their own vitamins. The author proposes that since these experiments suggest ragi can synthesize its own vitamins, it explains why the crop can flourish on soils where many other plants cannot thrive.

Physiological investigations relative to ragi have touched on some very interesting aspects. Unfortunately, these problems have not been investigated in depth and several of the more interesting facets have been unconfirmed by subsequent and follow-up experiments. Perhaps some of the most interesting facets for future study might consider why ragi seeds will stand storage exceptionally well, even as long as thirty to fifty years. Other fascinating topics might include the photo-synthetic activity, particularly at low latitudes and medium to high elevations. Superficially, the Eleusines have a very interesting plant structure in their somewhat flattened stems and long, slender, narrow, V-shaped leaves that tend to bend down about midway of their length. Similarly the efficiency and utilization of water in this species would be most interesting. There is considerable emphasis on the fact that ragi is better adapted to humid damp conditions and in association with paddy, but very little knowledge exists of its water use and drought tolerance characteristics suggested by some of the investigations related by Krishnaswami and Ayyangar (L.C.) and Rao *et al.* (L.C.). Another very interesting and important aspect is the germination and growth of ragi under low temperatures. Although predominately a tropical crop, this characteristic may suggest its use in temperate regions as well. Certainly, *E. indica* has been shown extremely adaptable in an extended range towards the higher latitudes.

Cytology and Cytogenetics

There are reasonably comprehensive records on studies on gross chromosomal complements in ragi, but the literature is relatively sparse or nonexistent in aspects such as embryogeny, chromosomal morphology and caryology, various cytological irregularities, and attempts to restructure the chromosomes. Virtually all of the cytological investigations conducted on this crop were carried out in India, and principally Tamil Nadu.

Chromosome Complements

The chromosomal complement in *E.coracana* was first recorded by Rau (1929) who studied the chromosomes in several millet species and in other crops. He found that *E.coracana* probably had 36 chromosomes and discovered that reduction in the anthers occurs only at night. Stages as early as telophase of the first meiotic mitosis were rare even as late as 6 a.m. in the Gramineae studied, which included principally sorghum and the millets. Krishnaswami and Ayyangar (1935) reported on haploid chromosome numbers in metaphase plants endogenous as follows: *E.coracana* = 18; *E.indica* = 9; *E. brevifolia* = 18; and *E.aegyptica* = 17. Secondary pairing was noted in *E.coracana, E.brevifolia* and *E.aegyptica.* They concluded that *E.indica* appeared to be a diploid; *E.coracana* and *E.brevifolia* tetraploids, and *E.aegyptica* probably a tetraploid with one pair lost (4 × – 2). The basic number was presumed to be 9.

Later studies of ragi, at Tamil Nadu concerned the embryology of this species at which time the chromosome numbers of some additional wild Eleusines were worked out and reported. These are *E.lagopoides* 2n = 36; *E.compressa* 2n = 45; and *E.verticillata* 2n = 36. Another genus which closely resembles ragi, *Dactyloctenium*, was also investigated. The basic numbers of the caryotypes were different, however, *D.aegypticum* had 2n = 48 and *D.scindicum* also had 2n = 48 chromosomes (Madras-DA, 1954). Sharma and De (1956) studied morphology of somatic chromosomes and found similar results, *E.indica* had 2n = 18; *E.coracana* had 2n = 36 and *E.aegyptica* had 2n = 45 chromosomes. They reported marked similarities in caryotypes within this genus and noted few meiotic irregularities in *E.aegyptica.*

Meiotic and mitotic observations were made and reported on several varieties of *Eleusine coracana* which had 2n = 36; *E.indica* and *E.verticillata* both with 2n = 18; and *Dactyloctenium aegyptium* with 2n = 36 chromosomes (Chandola, 1959). Meiosis was found regular in Eleusine, Setaria, Pennisetum, and *D.aegyptium.* Stoma and pollen-grain size were considered to be the criteria of polyploidy in Eleusine and the other millets. Secondary association suggested that Eleusine and Dactyloctenium had X = 7 while in Setaria it was X = 5. It was suggested that *E. coracana* may have originated as an allotetraploid from crosses between parents each with n = 9 chromosomes.

Other confirmatory evidence on the chromosome number in *E. indica* was reported by Singh (1965a, 1965b). Both pollen grain mitosis and root tip cells were used in these studies. Recommendations were made on the use of emergent earheads to study pollen cell mitosis according to the following procedure:

1. Fixing in 1:3 acetic-alcohol + 2–3 drops of saturated ferric acetate solution. Leave in a safe place for 7–10 days; repeat with 0.002 M 8-hydro-oxyquinoline or para-dichloro benzene can be used before fixation to disorganize the spindle and shorten the chromosomes. (The latter procedure is not recommended.)
2. Storing in 70% alcohol at 15–18°C.
3. Staining in Feulgen and squashing in 1% acetocarmine instead of 45% acetic acid produced better differentiation of chromosomes.
4. Hydrolysis for 10 minutes in normal HCL serves to change nucleic acids into aldehydes and softens the pollen grain wall.

The author considered this method more convenient than waiting for seeds to provide mitotic divisions.

The evidence from genetical and cytological studies suggests the cultivated species of Eleusine to be an allotetraploid by the presence of duplicate and polymeric factors. It is quite evident that *E. indica* is an immediate ancestor of the cultivated species. As previously suggested, however, there may be intermediate forms such as *E. africana*.

Embryogeny.—Studies on the development of the ragi panicle and floral organs, microsporogenesis, the pollen grain, megasporogenesis and embryogeny generally have been described by Krishnaswami and Ayyangar (1937), and Madras-DA (1954). These studies showed that the 18 pairs of somatic chromosomes of *E. coracana* are all more or less uniform in size and shape; and the microsporogenesis is typical. Occasionally, one or two univalents occur in the first division. They usually get included in the second division. Secondary pairing is evident. Megasporogenesis is also typical, the innermost of the linear tetrad functions. Polar nuclei remain separate until the first division. The primary endosperm divides at the neighborhood of the egg; thus embryogeny is typical. The antipodals are three and are very large, they are of the passive types. Grain threshes free of the glumes and hence the pericarp is ephemeral, only the inner seed coat persists.

Microsporogenesis.—Pollen development was studied and reported by Narayanaswami (1952). The anthers are bisporangiate and quadrilocular in cross section. The pollen mother cells are surrounded by a glandular tapetum of binucleate cells, a middle layer which is obliterated at an early stage, an endothecium developing fibrous thickenings and an epidermis containing attenuated cytoplasm and nuclei when mature. The pollen mother cells round up prior to meiosis and the divisions are of successive type. Usually the tetrads are isobilateral or tetrahedral in arrangement; but linear, decussate, and T-shaped, or tetrads are also frequently formed in the same loculus. These dispositions have not previously been reported in any of the grasses, although recorded in some monocots such as Musa, Hobenaria, and Ottelia.

A somewhat striking parallelism is observed in the behavior of the pollen mother cells and the megaspore mother cells not only in the formation of various kinds of spore tetrads, but also in the non-functional character of some of the spores of a tetrad. The pollen grains are 3-celled at shedding; the vegetative nucleus is always found in an advanced state of degeneration and takes a deep stain. Occasionally, super numerary nuclei are observed in the pollen grain. These can arise from divisions of the vegetative or generative nucleus (similar to Sorghum, Panicum and Paspalum).

Male gametophyte.—Narayanaswami (L.C.) also records a new feature found during the division of the generative cell. The two chromosome sets may move apart to the poles without the formation of an intervening cell plate. Such cells show two nucleoli of equal size lying side by side within a common nuclear membrane. It further appears that there may be no strong metaphase contraction of the chromosomes so that the resulting nucleus is diploid in constitution. This phenomenon is intranuclear and suggests a type of endo-duplication of the chromosomes as recorded in the tapetal cells of *Spinacia*. The formation of such cells, though sporadic, may be seen in the same loculus along with the normal pollen grain.

There are apparently few such similarly originating and apparently diploid male gametes in other plants. Fertilization of the haploid through functioning of such a diploid male gamete may be a causal agency for development of autotriploids in *Sacharum spontaneum* and in *Pennisetum typhoides*.

Chromosomal Irregularities

Dicentric chromosome.—A naturally occurring dicentric chromosome in *Eleusine coracana* was reported by Singh (1965). He observed chromosome numbers varying from 30 to 36 in the root tips of plants grown from three to four-year-old seeds of an Indian variety. The lower chromosome numbers were apparently caused by the loss of dicentric chromosomes as bridges in anaphase. The percentage of odd numbers at metaphase was consistent with that of fragments found in anaphase plates. Examination of the secondary roots showed that recovery of the normal 2n = 36 chromosome number had occurred. Collections from Uganda were also observed to have the same number of chromosomes to an equal of 36 in this same study.

Sterility.—A type of sterility was studied and worked out by Madras-DA (L.C.). One of these was found to result from segmental interchange between two pairs of chromosomes, another was a simple mendelian type resulting in the non-dehiscence of anthers. A third type affecting the spike as a whole and reducing seed set intermittently was called 'gappiness'. This was found to be the result of suppression of the spikelet primordia on the rachis. Cytologically, however, no disturbances were found. The inheritance of this latter type of sterility appears to be resulting from multipic factors.

Mutagenic and Polyploidizing Agents

Effects of X-rays.—Ragi plants treated with X-rays were reported by Krishnaswami and Ayyangar (1942). They compared the effect of X-rays in creating abnormalities in both *E. coracana* and in *P. typhoides*. In Eleusine, white-banded leaves, foliation of the panicle and truncated panicles arose as recessive abnormalities. In *P. typhoides*, X-ray treatments produced recessive characters, such as, sterility, gappiness, forking and goose-necking in the panicle and weak mid-ribbed leaves. In both plants the mutations were restricted to special plant characters, however, *P. typhoides*, a diploid, threw out more mutations than *E.coracana*, a tetraploid.

Polyploidization. There is one reference to the use of colchicine in polyploidizing *E.coracana* by Ono (1947). He found that the induced *E.coracana* polyploids were much less fertile than the diploids, although the grains were considerably larger. This was in contrast to the barley tetraploids which frequently had fertilities over 90%.

The dearth of reported investigations in cytology and cytogenetics of Eleusines is illustrated by the lack of information on caryomorphology of the chromosomes, absence of studies on chromosomal abberrations and irregularities, and investigations of interspecific crosses. Although a number of characters controlling specific factors in the Eleusine plant have been identified genetically, these are not related to specific cytological mapping areas, nor has there been any attempt to relate abnormalities with occurrences of chromosomal behavior. This field should be very profitable for future investigations.

Genetics

The major contribution on genetics of *E.coracana* is provided from India. Almost without exception, the early studies on inheritance of economic characters was carried out by Ayyangar and his associates at Madras, in fact, Ayyangar (1932) gave his presidential address to the Indian Science Congress of that year, the subject entitled 'Inheritance of Characters in Ragi, *Eleusine coracana* Gaertn.'

Inheritance of Characters

The work done at Madras was also summarized by the memoirs of agriculture (Madras-DA, 1954; Chavan and Shendge, 1957; and Leonard and Martin, 1963). Ayyangar noted at the time of his address to the Indian Science Congress that 13 independent factors had been accounted for, including B_1, B_2, C_1, C_2, C_X, D, E, I_1, I_2, Q, S, X, and Y. At this time no linkages had been found amongst these characters.

Plant pigmentation.—There are two basic kinds of pigmentation in ragi plants. These are green and purple and within each category there are several shades and intensities. Ayyangar (L.C.) and Ayyangar *et al.*, (1931) describe two shades of green. A light-green pericarp was found to have an average of 9 chloroplasts per cell in the pericarp as opposed to 14 chloroplasts in normal plants. The F_2 segregation from a number of natural crosses suggested that this character is a simple recessive and independent of factors influencing purple plant pigmentation and brown grain. This lighter green color appeared to be associated with a reduced depth of tint of the dried anthers. The normal green pericarp was identified by the single dominant factor Cx; whereas the recessive character, cx, produces a light-green pericarp color (Ayyangar *et al.*, 1931).

Purple pigmentation, mainly in the earhead, which gives certain varieties a characteristic violet color when in full bloom, is dominant to the unpigmented (green) condition (Ayyangar and Krishnaswami, 1931). Localized purple and green are differentiated by a single factor, Pp. One intensified factor, I_1, acts with PP basic purple to form dilute purple. Another intensified factor I_2, acts only in the presence of I_1 to produce full purple in the floral bracts and nodal bands. The following illustrates the plant pigmentation color and the genetic factors responsible for them amongst the Indian ragis:

Purple Groups		*Green Groups*	
$PPi_1i_1i_2i_2$	local purple	$ppI_1I_1I_2I_2$	green
$PPi_1i_1I_2I_2$	local purple	$ppi_1i_1I_2I_2$	green
$PPI_1I_1i_2i_2$	dilute purple	$ppI_1I_1i_2i_2$	green
$PPI_1I_1I_2I_2$	full purple	$ppi_1i_1i_2i_2$	green

In later investigations, Ayyangar and Wariar (1936) found a fourth type of purple which they referred to as medium purple. These four purples were found in Indian ragis; however, a deeper violet-purple color was observed in an African introduction from Malawi. The factors P, I_1, I_2, H_1 and H_2 were used to designate the first four pigmented types and Vt designates the violet-purple African type. Vt is a simple dominant to vt which is present in all Indian varieties of ragi. Vt could be detected in all grades of purple excepting localized purple on which its effect is light. It could also be present in a green (non-purple pigmented) lacking the factor P. The factor Vt is not conducive to economic growth under Indian conditions as the plants carrying it were relatively less vigorous. The significance and importance of the purple plant pigment is not very clear except in one case where pigmented types of ragi were found more resistant than non-pigmented ones to the blast disease of this crop (Rao 1947-48).

Panicle colors.—This covers the fourth purple kind of pigmentation which has been named medium purple. It is manifested in the earheads in dilute form, but the vegetative parts of the plant bear the full pigmentation characteristic of the purple form. Segregation ratios from crosses between the different purple types led to the establishment of two new factors labeled as H_1 and H_2 which, in combination, give a scarcely perceptible intensification of the color imparted by each separately. They also have a negligible effect in the absence of one or both of the previously mentioned intensification factors. This factor is identified as primarily affecting the earhead because it is in the earhead where it can be most easily detected (Ayyangar *et al.*, 1933).

Grain colors.—Brown is the predominate grain color in ragi, although a very few varieties have white seed. A brown pigment is confined to the testa, or the outer layer of the seed coat. In a cross between white grain, green plant, brown grain, purple plant, duplicate factor B_1 and B_2, either alone or together, produced brown grain. A third factor, S, in association with either B_1 or B_2, or both, produced purple plant pigmentation. A fourth factor, D, deepens the brown color and behaves as a simple dominant and is independent of the purple pigmentation factors. This accounts for the absence of white grain ragi in purple pigmented plants. Green pericarp of young developing ragi grain was found to be determined by a single factor, Cx. The recessive factor, cx, produces a light green pericarp color of the grain. This factor, Cx, is independent for the factor for plant purple pigmentation and grain color (Ayyangar *et al.*, 1931a). The green pericarp color is associated with a dry anther mass color of pale orange-yellow and the light green pericarp is ivory-yellow anther mass.

Panicle shapes.—There are two broad groups of panicle shapes in ragi—*Eleusine coracana* (Gaertn.)—those in which the digitate spikes of the inflorescence curve in and those in which they are open. A factor for density, designated Q is responsible for the close packing of spikelets on the rachis and is present in the curved, and absent in the opens. The curved are separable into In-curved and Top-curved. In the In-curved, the spikes curve in. The Top-curved are longer than the In-curved and in these, only the tips of the spikes curve. A second factor, E, determines the elongation of the rachis and separates the Top-curved from the In-curved. The E factor is also present in the Opens and its presence or absence gives rise to two groups, the Long-opens and the Short-opens. Their separation is difficult but their existence and individuality could easily be demonstrated from segregates with Top-curved and In-curved, respectively. The fingers of the In-curved are short, curve in and practically close up the central hollow giving the earhead an obovate shape. The fingers are longer in Top-curved with the result that they retain the central hollow. In the Opens, the fingers are the longest and present a characteristic funnel-shaped appearance. On drying, they curve out slightly, so that the best time to study these characters is in the milky stage on the primary or 'thumbed' heads. The length of fingers in Short-opens and Long-opens generally ranges from 7–12 cm in the former and from 10–19 cm in the latter, thus they overlap slightly but can be proved separate genetically by studying the segregation of crosses between the two parental types. The factors Q and E were found independent of the factors for plant pigmentation — the purples. (Ayyangar 1932; Ayyangar *et al.*, 1932).

In a continuation of the head characters, Ayyangar *et al.*, (1933) described a new head type referred to as 'fist-like', with fingers compactly In-curved. There appeared to be two factors, E_1 and E_2, which determined the elongation of the fingers, and which act in the presence of the factor Q resulting in curving of the fingers through increased density of the spikelets. When neither of the E factors is present, the finger length is very short, and in the presence of Q the form is fist-like. Either alone gives the short finger as previously described, while both together give the long finger with the corresponding Top-curved and In-curved forms when the factor Q is present. All three of these factors were found independent of the various plant, grain and unripe pericarp color factors described earlier. Later studies showed that these two genes, E_1 and E_2, also exerted an influence on other characters such as height and peduncle length (Vijayaraghavan and Wariar, 1948). An economic mutant having semi 'tight-fisted' fingers was discovered in a half-acre population of E.C. 593 ragi from Coimbatore grown at Hagari, Karnataka. This line was labelled as R. 42, bred true and was increased. It was green throughout, averaged 89.5 cm tall, had 6.4 fingers, each 6.2 cm long, and peduncles 23.6 cm long. It produced 9–10% higher yields than E.C. 593 normal over a three-year period 1935–37. It behaved as a simple recessive to the 'Top-curved' E.C. 593 (Vijayaraghavan and Sarma, 1938).

Abnormal spikes. These have been studied in ragi and have been described by different botanists. The presence of adventitious floral organs, associated with the absence of the 'thumb', was noted in several plants of the finger millet E.C. 4713 at Coimbatore. This character was not heritable (Venkataraman and Samathuvam, 1963). Sivagnanam (1961) also studied the secondary branching of the rachis and found it was non-heritable. Divakaran *et al.* (1952) found progenies of a single plant selection to give a 3:1 segregation for normal plants and individuals with leafy shoots replacing spikes. This abnormality was not fully explored but the analogy was drawn of a similar character in rice arising as a result of the deficiency of two chromosomes.

Glume length. An African variety of ragi having long glumes compared with the normal short-glumed Indian strains was crossed with one of the latter. Short glumes were found to be dominant to the long glumes and segregation in the F_2 and F_3 suggested the presence of three dominant factors identified as Gl_1, Gl_2 and Gl_3, all three of which are necessary to produce short glumes. Any two of these together in the dominant condition produce medium glumes, while one or none gives the long type glume. This type of interaction gives an F_2 segregation of 27 short; 27 medium; 10 long (Ayyangar and Wariar, 1936).

Sterility. Chronic partial sterility occasionally found in ragi results in very poor seed sets. Such plants grow profusely, flower late and have a low bushy appearance. Sterility results from non-dehiscence of the anthers or agglutination of pollen grains. The absence of a dominant factor, X, causes non-dehiscence, while the absence of the dominant factor, Y, causes pollen agglutination (Ayyangar and Krishnaswamy, 1931).

Albinism.—Albinism occurs in the absence of either C_1 or C_2 or both dominant independent factors for green plant color. These factors segregate in the di-hybrid ratio of 15:1. (Ayyangar and Krishna Rao, 1931). A similar segregation was observed in *E. indica* occurring in the importations from Africa. Albinos occurred in ratio of 15 green to 1 albino in this material. Amongst the green segregants some produced all green seedlings, some gave a 15:1 ratio and others gave a 3:1 ratio, thus paralleling the case in *E. coracana* (Ayyangar and Wariar, 1936).

Polyembryony.—In 1929 a number of seeds of ragi germinating in the millet nursery at Coimbatore produced two seedlings from the same seed (Ayyangar and Krishnaswami, 1930), the most common of these twin seedlings possessed two plumules and two radicles; but very rarely, two plumules in one coleoptile with a single radicle, or a single plumule with two radicles were observed. These twins occurred in ratios of about 1 to 1,100 seedlings in more than 4,000 seedlings germinated. The investigators suggested that polyembryony may arise in one or more of the following ways: (1) from the cells of the nucellus, (2) from the cells of the integument, (3) from the normal occurrence of two eggs, (4) from synergids, (5) from antipodal cells, (6) from endosperm cells, and (7) from the suspensor.

Vivipary.—Vivipary was recorded in *E. indica* in plants growing at two localities near Brisbane, Australia. The inflorescences were proved to bear proliferated spikelets, but the subtending glumes were normal with lemma slightly modified into well-developed leaf-shapes with bases and ligules. Development of the palea and flower were inversely related to the amount the lemma was modified. These bulblets were similar to those of *E. coracan* and *Festuca ovina* which also grow readily if detached from the parent plant, but in this instance the *E. indica* bulblet failed to develop. He also mentions similar vivipary in this species to have been reported from Foochow in China (Clifford, 1959).

Toppling.—The term, toppling, was coined by Divakaran (1960) for a kind of lodging which occurs in the reniform grained type of *E. coracana* and is characterized by indiscriminate falling of the culms in all directions irrespective of weather and soil-fertility conditions. According to data from E.C. 46·8 (toppling × Co. 1), toppling depends upon double recessiveness of duplicate factors.

Reniform grains.—Reniform, or kidney-shaped grains have been observed among seed samples of *E.coracana* studied at Coimbatore, Tamil Nadu. These seed types appear in African samples and are slightly heavier than the normal globular grain (Divakaran and Krishna Rao, 1952).

White-grained ragi.—The high-yielding, white-grained ragi strain E.C. 4310 was developed from a cross E.C. 1540 × E.C. 985 at Coimbatore, Tamil Nadu. The parent, E.C. 1540 is a low-yielding, white-grained strain with a high vitamin-B content, and originating from the white-grained E.C. 1008, a brown-grained type. E.C. 985 is a high-yielding, brown-grained strain, whereas, E.C. 4310 has a protein content of 8.4% compared with that of the brown-grained standard Co. 1 which has 7.5% (Wariar and Divakaran, 1956).

Genetic diversity.—A world collection of *E.coracana* germ plasm was collected and assembled in India during the period 1959 through the mid-1960's. The bulk of this collection was obtained from the systematic all-India collection of millets and maize during the period, fall of 1959 through the spring of 1963 (Rachie, 1965). This collection in its entirety was studied in several nurseries under different eco-geographical conditions in India. Typically these varied from Delhi at about 300 m in the north and 29° North Latitude to the intermediate elevation station, Wellington, Tamil Nadu at about 1,800 m and 12° North Latitude. The Indian collections were kept separate by states and their range in variability was studied in this manner. Total variability was quite considerable as indicated by the range in plant height from 16 cm to 145 cm, in basal tillering from 1 to 32, in number of ears per plant from 1 to 70, in number of digits per main ear from 2 to 57, in length of the longest finger from 2 to 15 ½ cm, and in weight of main ear from 0.2 to 13.7 gm. Values for the collection from each of the Indian states is presented in Appendix 5.

Of special interest were those stocks which responded well to high-fertility levels. Thus five outstanding stocks were selected in high-fertility nurseries grown at Bangalore in the spring-summer of 1965. These included I.E. numbers 5, 27 and 28 from Andhra Pradesh; I.E. 267 from Gujarat; and I.E. 378 from Tamil Nadu. Their characteristics are presented in Appendix 6. In trials, some of these lines frequently exceeded 6–7,000 kg per hectare under favorable conditions (Srinivasan *et al.*, 1965).

CORRELATIONS

The means and variances of certain characters for genetic stocks from South India were studied intensively. The highest values for means and variances for characters like number of ears per plant, number of basal tillers, length of ear and weight of main ear were exhibited by the collections from Tamil Nadu. However, for the character, number of digits on main ear (fingers and thumbs), the highest values of means and variances were found in collections from Andhra Pradesh. For plant height, the lowest mean value and highest variance were shown by the Karnataka collection. For maturity as determined by number of days to flowering, the highest variance was observed in types from Tamil Nadu, the lowest mean values were observed in Karnataka collections.

The relationship between number of digits and weight of grain in the main ear was studied in collections from Andhra Pradesh by calculating correlation co-efficients. Collection numbers I.E. 8, 11, 12, 16, 18, 21, 22, 23, 24, 25, 26, 31, 33, 34, and 35 showed significant associations while the correlations were insignificant in the remaining collections. The means and variances of selected characters in South Indian collections are presented in Appendix 7 (Srinivasan *et al.*, 1965).

SPECIES RELATIONSHIPS

An attempt was made by Mehra (1962) to gain insight into the relationships and evolution of the cultivated species of *E. coracana* in Africa. He studied a collection of 35 plants taken from a farmer's field at 5,000 ft. elevation in Uganda. The presence of natural hybridization between *Eleusine coracana* and *E. africana* is postulated, based on studies of pictorialized scatter diagram methods (Anderson, 1957) utilizing six morphological characters, including: (1) width of rachis, (2) width of stem, (3) length of spikelet, (4) length of glume, (5) length of lemma, and (6) width of raceme. By this method four groups were established and are described as follows:

Group I. This is identified as *E. africana* having an association of the following characters—thin rachis, thin stems, thin racemes, long spikelets, long glumes and long lemmas. The spikelets are widely spaced on the racemes and dehisce before maturity. The hybrid index was found to be between six and seven.

Group II. This was identified as *E. coracana* (African Highland type). It had thick rachis, thick stems, thick racemes, long spikelets, long glumes and long lemmas. The spikelets do not shatter and the grains are enclosed within long lemmas. The hybrid index was either eleven or twelve.

Group III. This was identified as *E. coracana* (Afro-Asiatic type). It had thick rachis, medium or thick stems, short or medium spikelets, short glumes, short lemmas and thick racemes. The grains are exposed and the lemmas and glumes are short. The hybrid index was four or five.

Group IV. Hybrids among the types above and showing various recombinations of other types are represented in this group. The hybrid index here ranged from two to ten.

Conclusions on Genetics of Eleusines

The knowledge of genetics in *Eleusine coracana* and its wild relatives is, like several other disciplines, extremely limited. Some excellent work was done on inheritance of qualitative, simply-inherited characters during the early 1930's by workers in South India. However, there has been relatively little added to this information since then. There is almost nothing written on the inheritance of quantitative characters nor on the nature of gene action in this crop. In fact, there is very little information on the components of yield and, owing to the unusual architecture of this plant, these may be assumed to be somewhat different from that of other cereal crops relative to the grain yielding potential of this species. Very interesting problems remain to be studied in these aspects, particularly in the knowledge of quantitative characters and in the nature of gene action of this species.

Considerable range of genetic diversity exists in the cultivated Eleusines. There appears to be exceptional potential for both grain and fodder production amongst the different genotypes within the world collection of this crop. The different head types described previously and the wide range in condensation of spikelets and racemes offer considerable scope for further development. Moreover, the great diversity of grain quality types offer nearly unlimited opportunities for recombining several desired factors. In particular, the malting qualities of this grain need to be studied for its potential industrial use. For all practical purposes there is no information on specific qualities of the nutritive values (protein and fiber content) and malting properties of the grain relative to identifiable genotypes. Thus, the breeding and genetics of this ragi offer an excellent future for rapid and profitable progress.

BREEDING

The breeding of ragi millet has been very largely confined to India, particularly in the south and the states of Tamil Nadu, Karnataka and Andhra Pradesh. There are, however, a few brief references from some of the other Indian states and from a few of the East African countries, including Uganda, Zaire, Malawi and Rhodesia. Some very limited testing work has also been reported from Sri Lanka, Malaysia and the Philippines.

The Importance of Breeding

The importance of ragi in India and in certain other regions has been noted by several investigators. Ayyangar (1932) pointed out the importance of ragi in South India and its potential. Gokhale *et al.* (1931) stated that ragi had been found to give very high yields under intensive cultivation and the grain also possesses high nutritive value, thereby justifying intensive efforts to evolve improved strains. Iyer (1954), Chavan and Shendge (1957) have mentioned the importance of breeding this crop and also did a brief review of the varietal improvement that had been carried out in India. Most of the improvement up to 1957 resulted from pure line selection of local varieties. In Tamil Nadu, sixteen strains had been selected and released. In Andhra Pradesh there were fourteen, in Karnataka, seven, in Maharashtra, three, and in Bihar two improved strains had been selected and distributed to the growing regions.

Although the early efforts on the improvement of ragi have largely concentrated on the development of pure breeding strains and varieties, Ayyangar (1932) proposed considering the development and improvement of composite varieties. This rather unorthodox view may not have been given very much thought in those times, but it nevertheless has proved highly prophetic insofar as current genetics and breeding have moved and developed. He proposed this technique in the attempt to develop varieties with a much greater range of adaptation to weather and climates prevailing under erratic rainfed conditions. He further theorized that such populations would contribute at least a small amount of heterosis by virtue of some natural crosses amongst the different genotypes comprising it. Nevertheless, all improved commercial strains that have been released are, insofar as is known, pure line strains, selected from local or other material and/or a combination amongst specific types.

Crossing Techniques

Eleusine coracana is very highly self-pollinated; estimates of natural crossing generally have not exceeded 1%. Moreover, the flowers are very tiny and extremely difficult to manipulate. Full removal of the anthers requires the use of a magnifying device and is such a difficult procedure that some alternatives have been considered and tried. Ayyangar (1934) has suggested the contact method of crossing by exploiting the dominance of certain characters in the pollinator parent. This involves removal of all except a single ear, finger, or portion thereof in certain varieties and pollinating the flowers by contact with the desired female ear and enclosing the two in a bag to prevent unwanted pollen. In normal emasculation the florets are selected the previous evening and anthers removed by opening the glumes with a fine-pointed forcep. Surplus spikelets are removed with a scissors. The next morning the selected pollen is dusted on the stigmas of the emasculated florets which overnight have been kept in a tube, the end of which is partially plugged with a piece of cotton. This hand emasculation technique has been successful to the extent of 60 to 90% when care is taken in each step of the operation.

As a result of the difficulty in hand removal of the anthers and the generally erratic results of the contact method, an alternative was suggested and tried by Rao and Rao (1962). They emasculated the ears by immersion in water at 47°C for 10 min, or at 48°C for 7 min. This treatment did not damage the other floral parts. Further studies on this technique were made by Raj *et al.* (1964) who found hot water emasculation was quite successful when treating the florets with hot water at 52°C for two minutes. A further refinement has been to use the contact method of pollination whereby a panicle of the desired pollinator with a length of peduncle is removed, immersed (the peduncle) in water and placed in direct contact with the emasculated spikelets. It is left in place for a few days until pollination is over. This combination of hot water and contact pollination has proved to be the best method of obtaining reasonable quantities of crossed seeds.

Selection Indices

Yields in relation to expression of various characters was studied in Maharashtra by Gokhale *et al.* (1931). They found that yields were related to interactions of numbers of ear-bearing tillers, number and size of earheads, density of spikelets and weight of individual grains. The contributions of the main panicle on successive tillers to total grain yield were studied in five varieties of ragi in Coimbatore by Samathuvam (1962). In the varieties AKP 1, AKP 2, E.C. 4713 and E.C. 4728, the main panicle produced about 40% of the total yield, while in Co. 7 the yields of the main panicle and the first three tillers were similar. He suggested that since the tillers were more important in Co. 7, this variety could be grown more economically in wider spacing.

Studies in the world collection maintained at the Indian Agricultural Research Institute at New Delhi, and grown en masse under several different eco-geographical conditions in India, led to some interesting findings by Srinivasan *et al.* (1965) and Srinivasan and Khanna (1967). They found certain characters could be used as selection indices to improve the grain and straw ratios, and thereby to increase grain yields. As a result, major breeding objectives were formulated from these investigations. The studies on variability in the world collection of ragi at New Delhi and Wellington, Tamil Nadu in 1963 resulted in formulating the following major breeding objectives:

1. *Height.*—Both grain and fodder are economically important in ragi in India; but grain is the more important and therefore medium plant height, or from 50–75 cm may be best.

2. *Tillering.*—Profuse basal tillering is considered desirable; but nodal tillering which contributes more to total yield may result in

uneven maturity and therefore causes the plant to be more susceptible to lodging since it would be later in maturity.

3. *Leaf characters.*—Telescoping of internodes may tend to increase photosynthesizing capabilities. Upright leaves may also be more efficient; but some investigations have found high straw production correlated with grain yields.

4. *Earhead characters.*—The positive correlation between number of digits and grain yield of the main ears suggests attempts to select for increased numbers of digits and increasing earhead size. Preliminary studies indicated that this character is inherited (branching of digits) but that it is low in penetrance and expressivity.

5. *Lodging.*—Resistance to lodging is an essential breeding objective which depends on plant height and several other factors.

6. *Resistance to diseases.*—Important diseases include blast, leaf blotch, downy mildew, smut, and more recently, the 'virus-disease complex'.

7. *Maturity.*—Different maturity groups will be required for the different conditions, however, early types are the more useful and should therefore receive priority.

8. *Grain quality.*—In this respect larger seed size would be desirable. White-pearly grains have also been found higher in protein and vitamin-B content and are preferred for producing ragi malt. White grain types however, are lower in productivity than the reddish-brown or brown types.

9. *Response to high fertility.*—Ragi has tremendous potential for grain productivity. High-fertility responsiveness would therefore be highly desirable. High population response appears to be closely related to high-fertility responsiveness. It may be that large earheads and profuse tillering are selection indices for both characters.

Statistical analyses of data obtained from studies on fifteen varieties at Coimbatore, Tamil Nadu, provided the basis for formulating a selection index for grain yield and the possibility of using a discriminate function for yield in *Eleusine coracana* (Mahadevappa and

Ponnaiya, 1963, 1965). They showed that the number of ear-bearing tillers, number of fingers per plant and the weight of straw per plant were components responsible for most of the variation in grain yield between varieties. From these it was possible to evolve a formula for selection purposes and they concluded the number of ear-bearing tillers and weight of straw per plant had the greatest effect on grain yield and should be used as selection indices.

Investigations and evaluations on the world collection of ragi in different parts of India have suggested the importance of providing the best possible conditions for the expressivity of the characters desired. This objective was followed in growing the world collection at Bangalore in the spring-summer of 1965 under high levels of nitrogen fertilizers up to 150 lb of nitrogen per acre. This afforded an excellent opportunity for selecting those strains which responded well to these fertility levels. These were then increased and included in subsequent uniform trials throughout the country. Some of the best of these, notably I.E. 28, 267 and 901, which were obtained directly from the collecting program in India, consistently proved superior under high-fertility conditions in several tests over a three-year period. Yields of the top varieties often exceeded 5,000 kilos per hectare where conditions were favorable (The Rockefeller Foundation—1965, 1966, and 1966, 1967). A fundamental aspect of the All-India Crop Improvement Program as established on ragi beginning in 1963, was the attempt to apply selection pressure over a wide range of environments and under high-fertility conditions; and to screen for disease resistance, particularly for diseases like blast.

Plant Types and Characteristics

The first record of classifying plant types in the cultivated species of *E.coracana* is recorded by Coleman (1920); he proposed groupings based on head type and glume color, which were classified either pure green or violet tinged, he also noted a smaller intermediate group having pale green glumes and found several seed samples, particularly those received from Maharashtra and U.P. to have yellowish-brown glumes producing light-brown seeds. The classification proposed for the Karnataka ragis is as follows:

Group I.—The glumes tinged with violet, the grains are reddish-brown, include spikes in-curved or compact and these are referred to as type I. The second is spikes straight or open, and is referred to as type II. Spikes branching is type III.

Group II.—Glumes green, grains reddish-brown. Spikes in-curved or compact—type IV, spikes straight or open—type V, spikes branching is type VI.

Group III.—Glumes pale green and grains white. Spikes straight or open–type VII.

A rare type, VII was observed having long spikes, or about 50% longer than normal and averaging about 80 mm in length. He concluded on the basis of these attempts of classification that (1) color of glume has no effect on yielding ability; (2) the straight spike types tend to yield more than those with in-curved spikes; (3) pure strains tend to yield substantially more than the normal mixture; (4) an inverse correlation exists between weight of earhead and tillering; (5) non-tillering (rather low-tillering), large head types may be more suitable for irrigation; (6) there is an appreciable difference between strains in respect to grain size and specific gravity, the grain is frequently sold in the market by volume rather than the weight; (7) heavier seed rates may be used to compensate for low-tillering; (8) mixtures (as commercially grown) are lower yielding and ripen unevenly. A description of the local cultivars of Karnataka are given by Coleman in Appendix 8. These and cultivars from other countries are also described in Appendix 9.

Finger length, type of ragi head, number of seeds per panicle and per centimeter of a panicle were studied in detail by Rao and Rao (1962). They found that there were no significant differences between the type of panicle (Open, Top-curved, In-curved and fisty type) and numbers of fingers per head, nor in the number of seeds per head. Often the number of fingers per head are controlled by an environmental influence. Sivagnanam (1960) found that seeds from the extra earheads produced normal plants. A ragi variant having shortened or absent internodes was studied by Divakaran in 1959. He reported that some types do not have internodes in portions of the stems resulting in a cluster of leaves arising at a single node. In such types the leaf sheaths loosen and break away as the head develops so that the stem is not supported, therefore lodging of the plant is common under this condition. This suggests that shorter internodes, rather than absence of internodes, might be superior to either of the longer types, and it appears that these types are better adapted for higher grain yield through increased photosynthetic efficiencies.

Breeding Progress in India

The major centers of ragi breeding in India have been firstly, Coimbatore, Tamil Nadu, with secondary breeding and testing centers at Anakapalle and at Koilpatti in the south part of the State. In Karnataka, much of the breeding work has been carried out at Hebbal near Bangalore, at Mandya about sixty miles south of Bangalore and to a limited extent, mainly for testing, at Karwar at the edge of the Western Ghats. In Andhra Pradesh, the millet breeder is headquartered at Guntur in the east, but work is also carried out at Visakhapatnam and in Chittoor. In Maharashtra, the major center for crop research has been Poona with subsidiary centers elsewhere. In Gujarat, the work on ragi has been carried out to a limited extent at a place called Waghai in the south-eastern part of the State. The Indian Agricultural Research Institute at New Delhi has done relatively little breeding work but has in recent years concentrated more on fundamental aspects related to maintaining the world collection and in respect to grain quality. Some work on this crop has also been done in the Himalayan foothills of Uttar Pradesh, in Bihar and Orissa.

Ragi breeding: Tamil Nadu (India).—Sixteen improved strains for Tamil Nadu have been developed and released mainly from the breeding center at Coimbatore. Work on these has been variously described in Madras-DA (1939–40); by Ramabhadran and Divakaran (1957) and others. A major objective in the breeding program at Coimbatore has been to develop early-maturing, high-yielding strains with wide adaptation. This is to meet the need for early-maturing crops which can be easily rotated with other major irrigated crops in northern Tamil Nadu.

Efforts to breed early strains were described by Sivagnanam (1960). Specifically, these varieties would be needed for the Chingleput and South Arcot districts where ragi is grown under irrigated conditions in large areas in two distinct seasons, from December to March, and from May to September. The variety grown in the December season is shorter in duration and is popularly known as 'kulla' ragi. In the May-September season, a longer duration crop known as 'perum' ragi is cultivated. In the shorter season groundnut is usually intersown about a month before the ragi is harvested, and the groundnut remains on the field until the next August after the ragi is harvested. The strains under present cultivation are AKP 1 and AKP 2 developed at the ARS, Anakapalli. Although early, both strains are not as high yielding as the other later improved strains of Tamil Nadu. Therefore, efforts to develop an early high-yielding strain for these irrigated conditions was initiated in Coimbatore in 1954.

The first step in developing short-duration genotypes was to collect and study a large number of representative, early types. Two of these, E.C. 4713 and E.C. 4728 obtained from Tellichery (Kerala State) and Nellore (Andhra Pradesh), respectively, recorded high yields coupled with a short duration. In fact, in two out of the three years, 1957–1959, these two strains outyielded the local standard AKP 2 by 60–208%; and in the third year, 1959 they produced slightly over 36% higher grain yields than the check strain. Straw yields were also higher in the two new strains being 14–104% higher than the check varieties. Moreover, they matured in 87–96 days compared with 93–101 days for AKP 2. In plant height they tended to range slightly taller, or some 45–82.5 cm compared with 42.5–55.7 cm for the check. Tillering ranged slightly higher, or between 2.5–3.5 tillers per plant compared with 2.2–5 for AKP 2. They had 7.4–11.8 leaves compared with 6.7–9 for the check. Length of the fourth leaf ranged from 22.7–40.7 cm for the two selections compared with 24.5–31.9 cm for the fourth leaf in AKP 2. Panicle length for them ranged from 4.5–5.7 cm compared with 4.9–5.2 cm for AKP 2. Number of fingers ranged from 4.5–7.9 for the two selections compared with 4.6–6.3 for AKP 2 (Sivagnanam, 1960).

The improved strain Co. 7 was first announced in 1959 by the Coimbatore Millets Center as a high-yielding variety maturing in 100 days and requiring less water than Co. 2 with which it was compared. It was also recommended for rotation with cotton in Coimbatore district on account of its early maturity (Subramaniam and Sivagnanam, 1959; Ponnaiya and Subramaniam, 1962). A slightly later strain, PLR-1, was announced in 1960 as a high-yielding selection from the local type 'perum' ragi and recommended for the main and summer crops in the Chingleput and South Arcot districts of Tamil Nadu. Its duration is 110 days (Subramaniam and Sivagnanam, 1960).

Co. 8, a very early strain, was announced in 1964 in replacement for AKP 1 and AKP 2. It is less than 90 days in duration and suited to both growing seasons for May to June and December to January sowing. This strain was derived from Karum-suruttai variety from Sulurpet and has outyielded local strains by 15–50%, with grain and straw yields frequently running up to 2,200 and 2,800 lb/A, respectively. It is also tolerant of blast disease (Madras-DA, 1964, 1966; and Shanmugasundaram *et al.*, 1965).

The development of high-yielding, white-grained ragi was first described in 1956 by Wariar and Divakaran (1956). This was identified as E.C. 4310, a derivative of a cross between E.C. 1540 × E.C. 985 made at Coimbatore, Tamil Nadu. The parent, E.C. 1540 is a low-yielding, white-grained strain with a high vitamin-B_1 content and originated from white-grained E.C. 1008 × a brown-grained type. The pollinator, E.C. 985 is a high-yielding, brown-grained strain. E.C. 4310 has a protein content of 8.4%, whereas that of the brown-grained standard Co. 1 is 7.5%. In 1962 the variety Co. 6 was developed from a cross between the white-seeded selection E.C. 1540 previously mentioned and the high-yielding, brown-seeded selection E.C. 2985. This variety has a duration of 120 days and produced high yields. The grain was found to have higher vitamin and protein content than brown-grained types (Rajagopalan and Samathuvam, 1962). In further trials with white-seeded types, Mahudeswaran *et al.* (1966) found that yields of white-seeded ragi varieties were generally less than those from brown-seeded types, but they contained a higher percentage of protein.

In trials of several improved strains in the lower Bhavani project area over a three-year period, the improved strains of Co. 3, PLR-1 and Co. 2 were found to out-yield the earlier strains, AKP 1 and Co. 7. The former three matured in about 110 days under those conditions (Palaniandi and Ananthapadmanabhan, 1966).

Karnataka (India).—The evaluation and testing of ragi varieties in Karnataka dates from the early 1900's, according to Coleman (1920). He reported on two years of testing in 1914–15 and found that two strains were generally at least 25% better than commercial mixtures of three varieties for the two years of tests. Moreover, the mixtures were found to ripen un-uniformly, increasing the expense of harvesting, or resulting in poor quality seed. Coleman described the local cultivars of Karnataka according to his criteria based on glume color and head types. These are included in Appendix 8.

Development of a short-maturing variety of ragi K-1 was described by Narasimhan (1940). This strain was selected in the Kar ragi area in Mysore district. In addition to the testing of local strains, trials in Mysore included introduced varieties and hybrid strains from RO-889 (Majjige) × RO-324 (Coxcomb) and many other selections at the Hebbal farm (Mysore-DA, 1950).

Further improvement has been described in publications by Iyengar and Lakshmaniah (1957) and Lakshmaniah (1959). Breeding work on ragi in Karnataka serves an area of nearly 2 million acres producing three-fourths of a million metric tons of grain annually, or about 35% of India's total crop. In view of the early recognition of the importance of ragi in this state, improvement work was initiated in 1913 and resulted in the development and release of several strains including K-22, K-1, ES-11, and RO-786 for general cultivation. Somewhat later there was a decline of interest in ragi and work was not resumed on this crop until about 1950 when it was organized at Mandya. During the ten years following 1950, several varieties were evolved including the following:

1. *Aruna.*—This strain was selected for the irrigated summer tracts. It has a duration of 105 days and is highly uniform—about 90% of the heads mature simultaneously. It is also widely adapted for both the summer and monsoon seasons (July sowings) and normally produces between 1,600-2,000 lb/A grain.
2. *Udaya.*—This was developed by hybridization amongst the parents Aruna, K-1 and Co. 1. Udaya (20-13-27) occurred as a cross between Aruna and K-1. It produced 36% more grain than K-1 and matured in 105 days. Udaya is 90-105 cm tall; has 3-4 tillers; has dark green leaves, hairy lower leaf surfaces and leaf sheath; has purple, open earheads; and uniform maturity (95%). The fingers are $2\frac{1}{2}$-3 in (6-$7\frac{1}{2}$ cm) long with a brittle rachis when dry. The number of fingers varies between 8 and 14; purpling is intensified in the glumes, basal ring, junction and nodal band. Udaya is widely adapted throughout the year except for October-November sowings. The seedlings should be 15-22 cm tall, and not more than 25

days old when transplanted at spacings of 10–12 cm apart in rows about 25 cm apart. The recommended fertility level of this strain is 30–20–30 units per acre.

3. *Purna.*—This is a cross between Aruna and K-1. It produces 40% more yield than Aruna, or as much as 2,600 lb/A; it matures in 105 days; is adapted to all seasons; is 68–105 cm tall; tillers moderately. The stems are rather thin, and it has a dilute purple band at the nodes. The leaves are green, hairy underneath, narrow, closely set at the base and do not flare away at the base when mature. The heads are purple and top-curved; the rachis remains soft and does not break when dry, nor does it shed. The number of fingers varies from 6–16 (averaging 9–10), and it is 90% uniform in maturing.

Andhra Pradesh (India). Breeding activities at Anakapalle and Visakhapatnam and Bapatla in Andhra Pradesh are described in publications by Naidu and Narasimhamurthy (1945), Narasimhamurthy (1956), Rao (1958–59), Rao and Narasimhamurthy (1962), and Rao *et. al.* (1956). The most important recently improved strains in Andhra Pradesh are VZM 1, VZM 2 and AKP 6. VZM 1 is an August to December selection with 37% higher grain yield than AKP 7 on the experiment stations where it was tested, and 13% better yields in district trials. VZM 2 is a December to April selection with 26% higher grain yields than AKP 6 on experiment stations and 14% more in district trials; it also has 5% more grain per dry ear weight than AKP 6. Both of these new strains are green throughout and not pigmented. At Bapatla, trials over three years were undertaken to compare the three most improved strains AKP 6, VZM 1 and VZM 2 grown on sandy soil, with splash-watering in the ragi season, or from December till March. Grain yields were found to be significantly higher from AKP 6 than from VZM 1. VZM 2, however, was the tallest and slowest to mature; AKP 6 had the most tillers per plant and the most fingers per head; and VZM 1 was the shortest.

Maharashtra and Gujarat (India).—The improvement of ragi in Maharashtra and Gujarat, which were once unified under the state of Bombay, has been discussed mainly by Pandya *et al.* (1955), Chavan *et al.* (1956), and Govande (1950a, 1950b). Ragi, or nagli as it is known in Maharashtra, is an important food and fodder crop of the highlands and also on the hill slopes. It is also cultivated to a limited extent in the plains of Gujarat and on the hill slopes. The first record of improvement of this crop dates to 1921 at the Agricultural Research Station located at Hathkamba in the Western Ghats. Work was also undertaken at Igatpuri in Nasik district and Vadgaon. Later work was shifted to a place called Waghai in the southeastern portion of Gujarat.

The work on genetic improvement of ragi at Nadiad was started in 1942 and resulted in the selection of three promising strains, namely, 47–1, 96–3, and 220–1, giving about 12–29% higher grain yields than the locals on the experiment station and on cultivator fields in Kaira district. In Baroda district, the selection 220–1 was the most promising. In Maharashtra, the improvement of ragi was undertaken in 1941 at Vadgaon, Poona district and at Igatpuri, Nasik district. At Igatpuri, the selection number 47, tested in Nasik district on cultivated fields, produced yields 10–15% higher than the locals. Meanwhile selection numbers 192 and 174 showed even greater promise than number 47 and were first tested in 1955.

In the Konkan, the improvement of ragi began in the year 1921 at Hathkamba. Three improved pure line selections were made including D–11 (early), D–31 (mid-late), and A–16 (late). These produced 11–24% higher grain yield than the local strains and were distributed for general cultivation in Ratnagiri district. Subsequently, in a cooperative program with the Indian Council of Agricultural Research, two selections, 28–1 and 50–1 were isolated as early and higher-yielding than D–11. They produced 20–25% higher yields than D–11. One of the mid-late selections was also found superior to D–31 giving 28% higher grain yield and another producing 28% higher grain yields than A–16 were identified and entered in district trials. Further work on the improvement of ragi in Maharashtra has been organized at Vadgaon in Karwar district, Wagai in Dong district and Karjat in Kolaba district. For Baroda, the variety Jagudan 44 ragi produced 17% more grain than local strains.

Bihar (India).—Three improved strains of ragi were tested over a three-year period in different growing regions of Bihar. These strains were A-402, A-404 and A-407. In the Sabour and Dholi regions, the local variety was out-yielded by A-407, and in the Patna and Kanke regions by A-404 (Nezamuddin and Akhtar, 1966).

Sri Lanka.—Ragi is grown at the intermediate elevations and on hill slopes in Sri Lanka, similar to the areas where this crop is cultivated in southern India. Experiments were conducted during the late 1950's in an attempt to identify high fertility responses in strains. The best of these were found to be No. 958, Co. 1 and Paul (Ceylon-DA, 1960).

Philippines.—There is very little record of ragi being tried in the Philippines. However, Jocson *et al.* (1959) included ragi among the other millets tested at Lamao during 1956–58. Finger millet consistently out-yielded the other millets, producing yields between 2,358 and 2,987 kg/ha. Finger millet was also more resistant to birds, insect pests and diseases, but tended to lodge and had the longest duration.

Breeding Progress in Africa

A viable millet breeding program has recently been developed at Serere Research Station (Soroti) Uganda (Peters, EAAFRO, Annual Reports, 1967, 1968, 1969, 1970). Other investigations have also been sporadically carried out near Kampala, Uganda at Makerere University; in Zaire under the former INEAC at Yangambi and to a limited extent in Tanzania, Malawi (Nyasaland) and Zambia (Northern Rhodesia).

Zaire.—Experiments and trials on ragi have been reported from Zaire during 1956 to 1958 (INEAC, 1956; 1958). In 1956, trials were reported at Nioka where the lines O-114 and O-228 produced over 1,700 kg/ha compared with 888 kg for the Kisozi variety of ragi. In this same trial, the lines O-106 and O-309 yielded 1,300 kg/ha of grain. In similar trials at Mt. Hawa in Zaire, the varieties Vuri, Lango and Omidu yielded between 1,500 and 1,800 kg/ha. In 1958 at Kiyaka and the Kisozi variety produced 2,371 kg/ha while the lodge resistant strains O-228 and O-114 produced 113 and 97%, respectively, of the control yield of 2,683 kg/ha at Nioka; and the taller O-308 and O-309 lines gave 120 and 98%, respectively, of the control yield of 2,312 kg/ha. At Mt. Hawa, Esuruva and local cultivars produced 1,200 and 1,176 kg/ha; while at Kisozi, lines O-9, B.K. and I.M. produced 1,368–1,266 kg/ha of dry grain.

Rwanda, Burundi.—The distribution of improved ragi for high elevations (above 1,900 m) has increased yields by 25% over the local Mphunsi, grown after burning the vegetation; and Agahagarika grown between other food crops. These improved strains, Kiega and 1-M of the Mphunsi type, and O-9 and B.K. of the Agahagarika type are being multiplied (Bruyere, 1958).

Uganda.—Ragi introductions from Zambia, Kenya, Ethiopia and India have been tested rather extensively at Serere Research Station, but they do not appear to be superior to the standard strains. At Kawanda the standard varieties from Serere were compared with local Buganda seed. Engenyi and Ekwahoit gave the highest yields, the former variety was also the highest yielding at Serere (Uganda-DA, 1947). Results from trials in the northern finger millet area of Uganda have shown the varieties Gulu E and Sere 1 to be consistently high yielding. Seed of these two varieties was increased for distribution by the Uganda Seed Scheme (Peters, EAAFRO, Annual Report, 1970). A broad gene pool of the collection was initiated in 1968 at Serere, thus entirely new strains are being developed.

Malawi.—The reports on a variety trial of *Eleusine coracana* at the Lilongwe station near Mzimba, was reported in Nyasaland Quarterly (Nyasaland-AQ, 1951). The varieties, Phagalala and Fumbata gave the highest grain yields of 1937 and 1880 lb/A, respectively at this location.

Rhodesia.—A briefer reference to the selection of high yielding strains of *E. coracana* in Rhodesia was made by Hill (1945) and the author concludes that the slow growing millets like Eleusines and Pennisetums are considerably lower yielding than sorghum and are therefore of lesser value for food consumption. He points out however, their chief advantage at present is their apparent immunity against stem borer attack under Rhodesian conditions.

Coordinated Ragi Improvement Programs

The Indian coordinated ragi improvement program was initiated in 1963 with the evaluation, screening and cataloguing of the World

Collections totalling 947 stocks at major research centers at Delhi, Bangalore, (Karnataka), Coimbatore, (Tamil Nadu): at high elevation (up to 2,000 m) at Wellington, (Tamil Nadu); and Mandya, (Karnataka). Concurrently, seeds of improved strains from the different ragi-growing regions of the country together with the best selections from the World Collection were organized and distributed as uniform trials commencing from the 1964 growing season. In the first year, one trial was conducted at twelve locations throughout the country. In 1965, two trials differentiated on the basis of maturity 'Early' or up to 70 days to flowering, and 'Mid-late' or 71–80 days of flowering were again distributed to 12 locations. A third preliminary trial of ten fertility-responsive ragis, selected from the nursery at Hebbal (Bangalore) in the early part of the year, was also conducted at four locations in the 1965 main season. Promising entries from the latter 'High Fertility Trial' were incorporated into one of the two advanced trials in subsequent seasons.

Three seasons of uniform testing revealed some of the entries had wider adaptation and proved superior over locations and seasons. Among the 'Early Group', these are: I.E. =744 (Co. 7 of Tamil Nadu), I.E.-28 (Vakalvulsa from Andhra Pradesh), and I.E.-846 (55–78–4 from Tamil Nadu). In the Medium or 'Mid-late group', they include: I.E.-267 (Champanpuda from Gujarat), I.E.-774 E.C. 926 from Tamil Nadu, and I.E. 901 (Serere = 5 Okiringi from Uganda). The strains I.E. Nos. 28, 267 and 901 were obtained directly from the collecting program rather than as exchanges with breeders. The advantage in grain yield of the best three entries over the local strains in both 1966 trials ranged from 8–14% as an average for 12 locations for the 'Mid-late Group', to 26–34% for 15 locations in the 'Early Grou . The grain-yielding potential of ragi under good management is indicated by the trial yields obtained in 1966 ranging from less than 1,000 kg/ha to 5,000 kg/ha at Delhi, where the best entry, I.E. 848 (MS 9694 GT from Tamil Nadu), produced 7,900 kg/ha of grain. I.E. 267 had also shown exceptional yielding potential in the irrigated summer (January sowing) crop at Bangalore in 1967, exceeding 80 q/ha in small plots.

Assuming that all the ragi growing regions of India, or 2.2 million hectares, had utilized the management practices adopted in the uniform trials on local varieties, grain yields would have been 4.4

million metric tons or 3.4 times the production in 1966. Sowing one of the two highest-yielding entries from the two trials would have added another 20% or about four-hundred thousand metric tons to this figure. Altogether this increased production of about 3.5 million metric tons of grain would have fed 25 million more adults consuming a high-cereal diet.

Ragi is believed to have a greater range of adaptation and uses than the present extent of cultivation suggests. An important objective of the breeding programs centered at Hebbal (near Bangalore), Coimbatore and Delhi is to explore new uses and adaptations of the crop. Specifically, these involve combining responsiveness to high levels of soil fertility; resistance to diseases like blast (*Piricularia* spp.), leaf spots caused by *Helminthosporium nodulosum* and *H. leucostylum*; resistance to lodging in adapted strains; and improvement of grain quality. Incorporation of the white-pearly grain character from Co. 6 (Tamil Nadu) or I.E. No.'s 65, 810, 819 822, 943 or 956—some of which possess up to 50% higher protein contents than the ordinary red or brown seeded types—is expected to increase the nutritive values and improve acceptability among the non-ragi eaters.

Studies on the amino acid balance, malting qualities, and fiber content in the World Collection of Eleusines are contemplated in the recently sanctioned All-India Millet Scheme. It should be noted that ragi is being utilized almost exclusively for malting in East Africa and to a lesser extent in the hilly regions of the Himalayas in northern India. The grain is an excellent source of calcium and is relatively high in fiber content (3.6%). The seed proteins, though generally low (6–7%), have a relatively favorable amino acid balance. It is moderately high in lysine (2.72% of protein); and high in tryptophan (1.28% of protein) and methionine (3.68% of protein). However, these values are available from unidentifiable genotypes and environments. It is assumed that considerable variation in these and other constituents will be discovered as surveys are made of the collection grown under uniform conditions.

A description of the world's improved cultivars is presented in Appendix 9 (a) and (b).

Conclusions on Breeding

Great potential productivity and usefulness of ragi would appear to merit vastly more attention as regards its improvement than as presently received to date. The fact that extremely high yields have been obtained with relatively unimproved strains, the wide range of adaptation of this crop, its relative freedom from pests and diseases, the great range in genetic viability observed in the World Collection, and the multi-purpose potential of the grain for food, malt and feed are important assets in mounting intensive efforts at the improvement of this crop for different regions and purposes. From the standpoint of utilization, the production of malt from appropriate strains of ragi has hardly been investigated. This characteristic, together with those of low fiber content, high protein levels and the enrichment of specific amino-acids, would be important aspects to be considered in the quality improvement of the crop. Even protein content, which traditionally had been considered exceptionally low in ragi, has been found by some recent investigators to be unusually high in certain cultivars (Stabursvik, 1969).

Major problems and difficulties in the improvement of ragi by breeding involve firstly its mating system, and secondly, the proclivity of the crop to lodge. In the former instance the very high rate of self-fertilization coupled with the extremely small size of flowers with consequent difficulties of emasculation may render the crossing of ragi extremely troublesome. This difficulty has been largely overcome by the hot water emasculation and approach crossing technique. Nevertheless, the number of such crosses and the quantity of seeds produced per cross is of necessity limited. The search and discovery of genetic or cytogenic male sterility would be a substantial breakthrough in the improvement of this crop by opening up the possibilities for effective population improvement according to modern genetic principles and breeding techniques. Fortunately, the quantity of pollen shed would seem adequate for wind-dispersion if such steriles were available.

The second problem, that of lodging, is particularly troublesome whenever fertility conditions are favorable and moisture is adequate. Nevertheless, the range of genetic diversity available in the World Collection of Eleusines and the means for readily screening for standability by applying high levels of fertility under moist conditions suggest the importance of screening for lodging resistance and incorporating this character into adapted high-yielding strains.

GROWING THE CROP

Adaptation and Use

Finger millet or ragi is unique amongst the millets in having a respectable relatively high average yield. However, it is not considered to be particularly drought tolerant compared with sorghum, pearl millet or some of the other minor millet species. Its ecology seems to place it in moderate circumstances in tropical regions. The minimal moisture for successful growing of the crop is around 35–40 cm per season, up to about 75 or 80 cm. It is often grown in association with rice, i.e. on the profile areas which are too steep or where moisture is somewhat inadequate to grow a good crop of rice. Occasionally it is irrigated on rice lands where seasonal moisture conditions are sub-marginal for a paddy crop. The range of elevation where ragi is grown is substantial. It occurs in tropical regions from nearly sea level to up to about 2,500 m. However, it is more commonly found in the elevations between about 1,000 and 1,800 m. Ragi is most frequently found on well-drained, sandy to sandy loam, lateritic and laterite soils with reasonably good water-holding capacity. While the crop will tolerate a notably high rainfall, it must have a well-drained soil. The fertility level of the soil can range from poor to good, but higher yields are invariably obtained where fertility conditions are adequate.

The motivations for growing ragi are of interest and important in considering its range of adaptation and use. Seldom is the crop grown on extensive scales probably because of its high labor requirement and difficulty in mechanizing peasant cultivars. However, for peasants in India or small-holders in African systems of agriculture the high labor requirements are of less importance than the relatively good yields, relative freedom from pests and diseases, the multiple uses of the grain and stover (the grain for both cereal preparations and making up malt or brewing), and the storability of the ripe grain. The latter characteristic is in fact one of the most important assets of finger millet. The grain will retain its viability and quality longer than any other cereal crop in hot humid areas with marginal storage facilities. In fact where storage is better and more sophisticated the grain is said to be storable for several decades, thus making it a very important famine reserve food. In India ragi is grown annually on about 2.3 million hectares mainly in the southern peninsular region of the country where about three-fourths of the nation's crop is grown. The major producing states are Karnataka, Tamil Nadu, Andhra Pradesh and Maharashtra. About 40% of India's acreage is produced in Karnataka, primarily in the six southeastern districts, Tumkur, Bangalore, Kolar, Hassan, Chitaldrug, and Shimoga. Coleman (1920) reported that during the period 1905–15 ragi occupied more than a third of the cultivated area and was the staple food for four-fifths of the people in the state of Karnataka at that time. An average of 0.44 million hectares were grown annually in Karnataka state, principally on red or lateritic loams as a rain-fed crop of hill slopes and uplands. There are two main crops. In areas where higher rainfall occurs, early varieties are sown in May and harvested in August and September. However, the major area is sown to late varieties in July that are harvested in November. The early varieties are known as Kar or Cidda ragi; while the later types are known as Hain or Dodda ragi. An irrigated ragi crop is also grown in many parts of India. As much as 0.4 million hectares have been estimated to be sown under irrigation. An irrigated ragi tract of about 7,000 acres occurring in the district of Mysore and the Talluk of Chauakere is described by Lakshminarasimhaiyya (1945–46). It is grown principally in the dry summer season, i.e. between February and May on red sandy soils with well irrigation. The crop is easily transplanted from nursery beds and after harvesting the plants are frequently grazed by cattle or sheep. A particular variety known as Kuruba ragi with violet branching heads is used for this irrigated crop.

Further south in the state of Tamil Nadu, ragi is grown throughout the year, but principally in two main seasons. The main season crop is grown from May to June, while the second season is from November to mid-January. The latter crop is called the *pyru* (the cool weather) crop. In paddy lands ragi can also be grown from December to January following a rice crop. However, the major season is with the commencement of the southwest monsoon in June to July. It is reputed to tolerate a certain degree of alkalinity but thrives on good arable land where the soil is a well-drained loam or clay loam (Madras – DA, 1954).

The cultivation of ragi in the states of Maharashtra and Gujarat has been described by Chavan and Shendge (1955) and by Pandya and Chaugale (1955). It is the most important minor millet in those two states (not including sorghums and pennisetums). In this region of India it is grown principally as a rain-fed crop on hill slopes and high-lying areas. It is also often associated with rice cultivation in the Konkan, Maval and Malnod districts where it is grown on lands too light or steep for paddy. It is also grown on fertile alluvial soils in southeastern Gujarat.

Ragi is also grown in other regions of India, principally in the Himalayan foothills in the northern portions of the states of Uttar Pradesh and to a certain extent in Bihar and Orissa. The hill tribes of the Himalayan regions of Nepal and Assam frequently cultivate ragi in the intermediate and lower elevations as a cereal and for brewing. However, its cultivation has declined in recent years being replaced largely by maize.

Sri Lanka

Ragi is perhaps the most important minor millet crop grown in Sri Lanka. Sithamparanathan (1958) describes ragi as the most widely grown cereal crop in the Maha chenas where it is particularly suited to the poorer-drained lower slopes which are too moist for maize or sorghum. It is the only minor millet of importance in the dry zone during the 'maha' or wet season. It withstands the relatively high rainfall conditions prevailing during this season. Owing to its potential and importance in Sri Lanka, improvement on this crop was undertaken at Maha Illuppallama. Open-headed types are preferred for the wet season and many of the Tamil Nadu improved strains were found superior to the local or indigenous types of Sri Lanka.

Malaysia

The potential for ragi cultivation in Malaysia was pointed out by Spring (1919). He proposed it as an inexpensive source of food for imported Indian laborers.

Africa

In Africa, finger millet is grown principally in the tropical belt, ranging from the east side from northern Ethiopia as far south as northern Rhodesia. There is a considerable acreage in the lake region of east central Africa and eastern Zaire. However, a belt of production occurs as an elongated finger extending from the southern Sudan and Zaire up to Centrafrique, the Cameroons and into northeastern Nigeria (Gayte-Sorbier *et al.*, 1960). It is even cultivated as far west as Morocco although to a limited extent (Niqueux, 1950). The largest acreages to be found in the continent are in Uganda, Tanzania, Ethiopia and southern Sudan. In the southern Sudan, finger millet is often grown on light or wet soil. It is usually planted in pure stands or mixed with grain sorghum, maize or sesame. Throughout much of East Africa ragi is an important rotation crop in the system of Chitemane cultivation. This consists of chopping down trees or lopping tree branches from a wide area, piling over a much smaller area, burning, and then sowing millet in the ashes at the beginning of the rains and without any further cultivation (Savile, *et al.*, 1958; Northern Rhodesia, Department of Agriculture, 1950; Parsons, 1960a, 1960b and 1960c).

Tanzania

A kind of primitive agriculture practiced in Tanzania is described by Lunan (1950). This consists of turning over grassy chunks of sod to form mounds about 3 ft. in diameter and 2 to 2 ½ ft. high. Sometimes trees and brush may be incorporated with the mound to be burned during the dry season. The first crops to be planted are beans, cassava, sweet potatoes, chickpeas and wheat during the first season from February to April. Following summer rains the mounds are broken and spread in November and finger millet or maize are sown on the flat. After harvesting these in July the mounds are again formed to cover the weed patches, resown to finger millet, and harvested the following June.

Uganda

The most important ragi producing country in Africa is Uganda where 433,000 ha were planted in 1963. Of these, 227,000 ha were in pure stand and 206,000 ha were mixed with other crops. The grains formed the principal foodstuff of the nilotic people of north Uganda and Teso (Burgess, 1962; Parsons, L. C.; Dunbar, 1969). It was formerly more important than now in the agriculture and diet of the Bakiga, Banyankole, Batoro and Banyoro. The importance of well-drained soils was emphasized by Dunbar (L.C.) who also pointed out that the root system was well-adapted to the use of rainfall during growth, but that it does not effectively tap the deeper soil water reserves in time of drought. According to Dunbar, finger millet is best adapted to the plateau areas of Uganda with reasonably assured seasonal rainfall. However, if the main rains are delayed after the crop is sown or if a drought occurs following the onset of rains, the yields are drastically reduced. Therefore, finger millet is often inter sown with the harduous sorghum in the drier parts of northeast Uganda. The distribution of finger millet in Uganda is zonal, running from north to southeast to northwest across the country. Within this zone production reaches its maximum in south Teso and north Bukedi. However, cultivation is also important on the west Nile plateau. On the plateau in the west of Uganda and in the highlands of Kigezi, where population pressure is increasing and the soil is becoming progressively poorer, the production of finger millet tends to remain static or is declining. However, it does increase in the relatively more fertile areas of newly cropped lands.

The negative aspects of finger millet culture, namely, the slash and burn system, were noted by Hursh (1966). As previously pointed out, this system not only provides fertilizer for the crop, but, more importantly, it sterilizes the soil and kills grasses and other weedy growth. However, subsequent repeated burning for grazing following the growing of the millet crop produces vast scrub areas of thorn Acacia, Brachystegia, Commiphora and associated species. In marginal rainfall areas this vegetation degenerates rapidly under heavy grazing and burning, eventually producing incipient desert conditions. According to the author, only one crop of millet can be grown every ten years if sufficient brush is available, but after the coppice becomes less dense, adjacent tree stems are slashed to provide enough fuel for burning and two or three acres may be used for each acre of the crop. Therefore, responsible authorities are attempting to outlaw the slash and burn system.

The Americas

There is no record of finger millet production in the New World, although there have been sporadic and feeble efforts at introducing the crop for trial purposes in different areas. A trial including *Eleusine coracana* together with other millets was reported from the Argentine by Mille (1953). Several southern U.S. experiment stations made attempts to grow ragi during the earlier decades of this century. Although reasonable success was obtained, the crop did not gain popularity and spread. More recently, distributions of seed have been made to Mexico and California. In fact, the World Collection of about 1,000 entries of Eleusines assembled in India was grown out at the Experiment Station at the University of California, Davis. The crop there grew very successfully in 1967, although flowering was much delayed in many cultivars owing perhaps to long day conditions. Yields of several small unreplicated plots exceeded 5,000–6,000 kg/ha in several lines. However, there is no report of continued experimentation in the State (Ruddell, 1968).

Far East

Ragi has undoubtedly been under cultivation in the hilly regions of southeastern Asia for a very long time. It is known in China as 'Ts'au-tsu' and in Thailand as 'Phakkhouay'. However, its importance in mainland China is relatively minor compared with the production of setaria millet and sorghums. Finger millet has also been tried or grown to a very limited extent in the countries of Taiwan, the Philippines and Australia. Among the millets tried at the College of Agriculture, University of the Philippines at Los Banos, finger millet gave a better performance in both wet and dry seasons than did *Pennisetum typhoides* or Siberian millet (*Setaria italica*). Two strains of ragi were tried, Strain A and Strain B (Solpico and Yambao, 1966).

Regional Cultural Practices

Ragi is primarily a peasant crop grown in developing regions. Cultural practices vary from area to area and for different situations as it is often grown on new lands or when slash and burn systems have been carried out. It is also frequently grown on cultivated lands as a rain-fed crop during one or two seasons of the year. In somewhat more favorable circumstances it can also be irrigated. Generally, however, it receives little fertilizer at least in the chemical form.

Crop Rotations and Associations

In some of the important growing regions ragi is sometimes grown as a single crop in a rotation. It may be followed by fallow or mixed with other crops grown by the farmer in the same season. In most situations, however, it is rotated with other field crops like sorghum, millets, cotton and tobacco as in Karnataka, India. In other parts of India, the dry crop is sometimes alternated with groundnuts, cotton, sorghum or millets. Spice crops like ginger and coriander may be grown or one of the many grams are included in the rotation. In the better fertilized areas and with supplementary irrigation, ragi may be grown either before or after crops of gingely, millet, bulrush millet, onions, sweet potatoes, chillies, tobacco, sorghum, wheat, gram or cotton. In rice-growing areas it may follow rice in rotation or be sown in seasons when moisture is short as a replacement for the paddy crops. In hilly parts of the Western Ghats in India ragi is grown under the K.U.M.R.I. system. The land is first cleared of vegetation brush, trees, grasses and weeds. This material is spread over the surface of the land and may be supplemented by adjacent tree growth and sometimes other crop residues. This dry vegetation is then burned. It may receive some supplementary mineral and if the slope is quite steep it may be ridged before sowing (Iyengar, 1945–46).

Mixed cropping with ragi is also very common in India. It is frequently grown in association with sorghum, bulrush millet, pigeonpeas, cotton, and gram. In mixed cropping, the taller crop is normally grown in fewer rows, proportionately, and quite far apart, often between 2–4 m between rows. If all components of the mixed crop are about the same height and have the same competitive effects, they may be grown closer together. For example, the less competitive crops like cluster bean and moth gram, may be sown in the proportion of one row to two rows of ragi. In some regions such as Tamil Nadu, the mixed crop may be sown or dibbled when the ragi is in the earhead stage. In this way a crop of groundnuts or cotton is planted and thus has no competitive effect with the maturing ragi.

In Uganda, finger millet often follows cotton or tobacco. These crops are usually fertilized and weeded so the land is both clean and relatively fertile for finger millet. In the north and central parts of Uganda, the millet is often grown in association with pigeonpeas. Other crops with which it may be grown in association include groundnuts, cooking bananas, sweet potatoes and cassava (Dunbar, 1969). In the Sudan, finger millet is often grown on light or wet soils.

It is usually planted in pure stands or can be mixed with grain sorghum, maize or sesame. The crop is normally sown broadcast and covered with a hoe in April or in September and usually at the rate of 8–10 lb of seeds per acre (Leonard and Martin, 1963).

Land Preparation

There is a considerable range in the methods of preparing land for sowing ragi. This ranges from virtually no preparation as in the slash and burn system to other areas where the land may be ploughed with the stick plough as many as 3 to 6 times followed by harrowing and sowing or transplanting. In other regions, depending on soil conditions and weather, the blade harrow working at 2–3 in. in depth replaces the stick or turning plough. Increasingly a small turning or moldboard plough drawn by bullocks is replacing the conventional Egyptian stick plough in parts of India. The turning of furrows improves both weed control and makes for a more friable seedbed, moreover it requires only one path compared to several. Following ploughing, the land may be levelled and clods crushed with a mallet, with a plank harrow, a log harrow or bullock cart. If the crop is manured with organic manures such as city compost, tank silt, cattle or sheep manure and chemical fertilizers, these are usually applied before, during or after the ploughing and harrowing operations to incorporate them into the surface layers of the soils.

Peasant farmers are frequently very sophisticated about handling and tilling their lands particularly if they have lived in the same area for a long time or for several generations. They understand very well the physical conditions of the soil as affected by season and moisture. With limited sources of power, they are much concerned about efficiency of operations. Therefore, they know precisely when the soil is at the proper condition of friability and moisture content for the most effective and efficient working. This is often at the beginning of the rainy season after one or two showers following which the surface inch or two is relatively dry. This imposes a limitation on the amount of land that a man can effectively cultivate alone or with limited animal power, and to some extent, the timeliness with which the crop may be planted. For this reason and because it results in better stands and higher yields, transplanting is often done with ragi on the better cultivated lands.

Seasons

One frequently hears in ragi-growing areas that the crop can be grown in any season assuming adequate supplies of moisture or rainfall. In most regions ragi is grown during the rainfed season which in monsoon climates in the northern hemisphere begins in May to July and tapers off in September-October, or if a bimodal pattern exists increases again in October or November. The major portion of the Indian crop is grown during the southwest monsoon, that is, planted in May to July. Additional acreage in southern India and Sri Lanka is grown when the northeast rains are received in October-November. In equatorial regions of Africa sowing usually follows the beginning of the rainy season if the rainfall pattern is bimodal. For example, in northern Uganda it is planted with the first or the main rains in February-March in the central and northern parts of the country as in Teso and Lango districts, whereas in Bunyoro and Toro it is sown in the second rains. The irrigated crop can, of course, be planted at any time of the year in regions where temperatures are high enough to support normal growth. In central and southern India the summer dry season between mid-January and July produces an excellent irrigated ragi crop. This season also has the highest insolation and lowest incidence of diseases and pests.

Fertilizing

Ragi is often grown without much fertilizer applied in the direct form. If it follows highly fertilized crops like tobacco, vegetables, cotton or sugarcane it may not receive any fertilizer, utilizing whatever remains in the soil from the previous crop. Obviously the same situation arises following the slash/burn system where it is the first or second crop in the rotation, and there is more than adequate residual fertility for the full crop of ragi. In peasant agriculture chemical fertilizers are frequently unavailable or unduly expensive. Therefore very little of the ragi crop grown until recently has received major nutrients in chemical form. This situation is of course changing rapidly in many developing countries with the recognition of the economics of growing higher-producing crops, the lowering of the cost of fertilizers, and higher prices being received for the produce. Traditionally, however, the major sources of applied fertilizers have been in the form of organic manures, that is, farmyard manure, compost or city compost, tank silt, earth from old village sites and sheep penning. Cattle or sheep manure is sometimes applied at rates ranging between 3 and 20 cartloads, i.e. 1½ to 10 tons per acre. Occasionally much higher rates of manure may be applied. Where sheep folding is practiced the rate is frequently 2,000–4,000 sheep per acre per night.

Although ragi has frequently been shown to respond extremely well to applied fertilizers, agriculture departmental recommendations are often quite low, often in the range of 10 to 40 lb of nitrogen plus about 20 lb of P_2O_5 in addition to a basic dose of organic manure or when ragi follows a heavily fertilized previous crop. There is relatively little information on fertilizer recommendations in Africa, however in the eastern and northern regions of Uganda, ammonium sulphate is recommended at the rate of 125 kg/ha broadcast as a top dressing when the crop is about 15 cm high and after weeding. This is said to increase yields by about 450 kg/ha of dry grain. Fertilizer trials conducted in ragi-growing regions have shown that much higher levels of the major nutrients will give economic yield responses. However, it is true that indigenous strains frequently lodge very readily or their yields may be limited in other ways as from disease, insects, inadequate moisture or other factors.

Green manuring has also shown good results where the conditions are favorable for this practice, that is, where the season is longer than required by the ragi crop but insufficient for two crops, or where a shorter rainy season, again inadequate for cropping, occurs before the major rains set in. A system of green manuring in India is described by Solomon (1957). Sunhemp (*Crotalaria juncea*) is sown at the rate of 10 lb of seed per acre as soon as the monsoon breaks. After about a month the sunhemp crop has grown to a height of 30 in and is ploughed in. Transplanting of the ragi crop from a nursery can be carried out a week later. This practice has increased yields by as much as 350 kg/ha of dry grain.

Planting

There are two main systems of planting ragi. The first of these is by direct seeding and the second is transplanting from nurserybeds. In direct seeding, the seeds may be sown broadcast, then covered by ploughing, harrowing, or trampling with animals. The broadcast seed is normally hoed or cultivated twice or thrice at intervals of ten days after about three weeks of growth. This, in addition to weeding, thinning and providing a surface mulch, also forces the broadcast ragi into rows. If the stand is uneven it may be gap filled with the thinned plants. After weeding and thinning with drawn implements, the stands may be weeded by hand once or twice. In Africa, where animal power is not commonly used, weeding is often carried out by hand by members of the family or on a communal basis with friends and neighbors. A kind of heavy hoe, or jembe, is used for this cultivation between rows while hand pulling is practiced within the row and beside the plants.

The second system of direct sowing consists of using a seeder. Many indigenous types of seeders can be used. In India, these often consist of a multi-tined cultivator with tubes running down behind each tine. These tubes are connected at the top to a seed divider into which the sower dribbles his seeds. Such seeders often consist of as many as 6 to 12 tines based 20–30 cm apart (8–12 in.) and averaging about 25 cm. The distance between plant spacings is frequently 15–20 cm.

Transplanting of ragi has several advantages over direct sowing. Not only does it result in the shortening of the growing season on the land, but it also results in far better weed control, better stands, and higher yields. Where labor is adequate during the period of transplanting, these advantages are considered to pay very well for the additional labor required. A further saving accrues from the reduced amount of seeds required from 10–30 or more kilograms per hectare down to only 3 or 4 kg for transplanting. Nurserybeds 100–150 cm wide and about 4 m long are prepared and sown about 3–5 weeks before the transplanting is to take place. The ratio of nursery to field area covered ranges between 1:30 and 1:10, i.e. between 300–1,000 sq. m of bed for each hectare of field land to be planted. The nursery seedbeds are frequently heavily fertilized with manure, ashes, compost and chemical fertilizers. The seeds are sown shallow and may be covered with a thin layer of dried compost or farmyard manure to reduce drying and hardening of the soil and to facilitate uprooting of the seedlings at a later date. The rates of manuring of the nursery on a hectare basis would be roughly 10 tons of dried manure and about 30–40 kg of elemental nitrogen in chemical form. The nursery seedbeds are also irrigated as required for good growth of the seedling. The seedlings are normally transplanted from three to five weeks after sowing and after growing to a height of between 12–15 cm. Unless the field crop is irrigated, transplanting is normally done during a rain and after the monsoon is well started so that the soil has a good reservoir of moisture. Plant populations in transplanted crops vary with variety, location and seasonal conditions. However, average spacings of about 25–30 cm between rows and 15 cm between plants would strike a reasonable average for most conditions.

Weeding and Inter-Cultivation

Direct broadcast and row seeded stands of ragi are often cultivated with tined implements drawn by draft animals. This is done twice or thrice at ten-day intervals beginning about three weeks or a month after seeding. This operation results in removing weeds, thinning the stand, particularly in the case of the broadcast one, and mulching the soil. Somewhat later the crop may be hand-weeded and hand-hoed once or twice. In regions where animal or machine power is not available the weeding and cultivation operations are usually carried out by hand. This may be done on an individual family or community basis. However, in areas where the slash/burn system has been carried out, weeding may not be necessary during the life of the crop since the surface layer of the soil was sterilized during the burning process. A top dressing of the crop with nitrogen usually occurs during this cultivation stage between a month and six weeks after seeding. The most common recommendation is about 20 kg of N per hectare. Pest control measures during the subsequent growth of the crop vary from place to place and circumstances; except for a seed dressing and perhaps scaring of birds, it is seldom considered necessary or economic to attempt either insect control or disease control measures.

Harvesting and Threshing

Ragi normally matures in 3–5 months after sowing. The ripe heads may be removed directly from the standing plants in the field or the plants can be cut at their base, tied into sheaves and stacked up to dry. Many cultivars ripen unevenly and it is frequently necessary to make two or more pickings to reduce damage from shattering, birds, weathering and other losses. This is particularly true for the irrigated crop in southern India. After the head is thoroughly dried, the grain is threshed out in peasant systems by beating with sticks, treading under the feet of animals, or by working a stone roller over them. The latter is considered the most efficient in India. It is, however, perfectly feasible to thresh the grain with machine threshers although combining may be difficult with present varieties owing to the unevenness of ripening and tendency to lodge at maturity. In some parts of India, the plucked earheads are heaped for a few days after harvesting to cure. These heaps may even be sprinkled with water to make them more pliant during the curing process. Following this curing they are threshed as usual. The threshed grain is ordinarily stored in pits in the ground, in vessels, bags or small jars. Ragi grain stores better than any other cereal crop and is less subject to both stored grain pests and moulds. It is reputed to retain its quality and viability even after decades of storage when conditions are reasonably favorable. Yields of ragi are frequently among the highest of the millets. In India the average yield for the entire country normally exceeds about 650 kg/ha. Average dryland crops are often around a thousand kilograms while the irrigated crop may exceed about 2,000 kg/ha. Similar yields are reported from Africa.

Management Investigations

Most of the work on management investigations in ragi have been carried out in India and in central Africa. In India, much of the earlier work was done in Karnataka, Tamil Nadu, Andhra Pradesh, and Maharashtra. Work in Africa has been reported in Ethiopia, Uganda, Kenya, Tanzania, Rhodesia and Zaire.

Land Preparation Experiments

Some early work on preparing land for ragi sowing in Karnataka was reported by Coleman (1920). Autumn ploughing was found to double yields from 382 to 758 lb/acre for pre-sowing ploughing. This early ploughing was believed to increase water absorbing capacity and perhaps aided nitrification. An improved or partially turning plough used in early spring increased yields almost 40% from 466 to 642 lb/acre for the three years, 1912–1914. However deep ploughing was not considered advantageous except when rainfall was limiting. In harrowing, a disc harrow was found to penetrate very hard soils better when worked two or three times.

Rotations and Associations

Experiments on crop rotations involving ragi were also reported by Coleman (1920). In experiments on ragi following ragi, groundnuts or gram (*Dolichos biflorus*) in Karnataka, it was discovered that groundnuts had a marked effect on increasing the yields of the following ragi crop by 33% or 1,466 lb over ragi after ragi during the three-year period, 1916–18. Ragi yield was also increased by 14% during the four seasons 1915 to 1918 when following *Dolichos* gram in the rotation. However, this rotation was considered unprofitable owing to the low returns of *Dolichos* in the alternate years. Other workers have found that ragi can be profitably grown in a mixture with other crops particularly with pulses and goundnuts. Puttarajappa (1942–43) described the growing of Kar ragi between rows of Togari pulse (*Cajanus cajan*). When *Cajanus* is sown in rows 6–8 ft. apart during the monsoon season, and with ragi planted between on May 8, the ragi was ready for harvesting at the end of September. The pigeonpea was then only in the bloom stage. After removing the millet, *Cajanus* plants tended to fill the spaces and matured after another 1–2 months. Pillai, *et al.* (1957) found that ragi mixed with groundnuts in Tamil Nadu produced the highest returns at Palur over other combinations of ragi or when ragi was sown alone.

Time of Sowing

The first date of sowing experiments that have been reported were conducted in Karnataka in India over a six-year period, 1909–1914 (Coleman, 1920). Treatments ranged from June 1 to August 1 and revealed that July sowings were best, giving from 1,180 to 1,256 lb/acre compared with June 1, 10 and 20 sowings of 720 to 773 lb/acre at Bangalore. The effect of sowing times on two varieties of ragi, E.C. 1000, an early strain and E.C. 24 a long duration strain, were studied in Tamil Nadu by Ayyangar *et al.* (1938). They found the optimum sowing time for the main ragi crop was June for the earlier strain, but that the later variety could be sown either in June or July. For summer or hot weather crops, December and January sowings were preferred to later sowings inasmuch as the duration tended to lengthen in later sowing crops. They also studied the effect of climatic factors on plant characters and found that the number of leaves, number of nodes, height of plant, length of peduncle, length and width of flag leaf, weight of straw, weight of the roots, number and length of fingers in the main earhead as well as grain yield were affected by climatic factors. However, they also found that ragi developed and matured relatively early when sown in any season if provided with adequate moisture, nutrients and good cultural practices at Coimbatore, Tamil Nadu (latitude 11° N). In the two varieties studied they found that grain yield was highly correlated with number of leaves on a main axis, number of nodes on a main axis, height of the main axis, width of the flag on the main axis, length of peduncle, weight of straw, weight of root, and number of fingers on the main earhead. The lowest correlations were obtained between grain yield and number of earheads (0.05–0.06) with duration (0.05–0.21) and with proportion of first harvest total grain (0.28–0.29). The agronomic characters least affected by time of maturation were length and width of the flag on the main axis, length of peduncle on the main axis (all having coefficients of variability between 8.7–12.2); also length of fingers on the main earhead (cvs 9.0–10.7), duration (cvs 5.7–5.6) and number of fingers in the main earhead (cvs 6.2–19.0).

Subsequent experiments were conducted by Ponnaiya and Appathurai (1953). They studied the optimum sowing dates for irrigated millets in Tamil Nadu. Generally, June-July was considered the best time for sowing millets except for *Sorghum subglabrescens* which fared better when sown in April. The optimum period for ragi, however, was June to August but none of the species studied performed well when sown during November to March. Later studies carried out in Orissa by Patnaik (1968) showed that timely sowing with the onset of the monsoon resulted in highest yields. He obtained significant differences in yield, days to heading, tillering and height. The highest yielder was V.Z.M.I, but this was late in heading under Orissa conditions.

Date of planting trials were conducted during the first rainy season in Uganda by Schumaker, *et al.* (1969). Results indicated that the availability of moisture from germination through the first three weeks of growth appears to be very important for the production of good grain yields.

Seasons and Genotypes

To determine whether varieties were better adapted in specific seasons, experiments were started in 1943–44 by the Madras Department of Agriculture (1954) with several distinct strains from Visakhapatnam district in Andhra Pradesh. These strains included AKP 1 and AKP 2 known as *punasa* or hot weather season from May to August/September; AKP 3, AKP 4 and AKP 5 of the *pyru* or cold season from November/December to April; AKP 6 and AKP 7 from the *pedda-panta* season which is normally grown in that region from August/September to November/December. These were grown in the three respective seasons, *punasa* or hot weather, *pedda-panta* or the main season and *pyru* or cool season. The results indicated: (1) that short duration types alone are appropriate for the *punasa* season, while the longer duration types were found lower-yielding and subject to particular areas during the hot weather season; (2) that short duration types of the *punasa* season are not physiologically different from those of the *pyru* or cool weather season and are readily interchangeable. Thus the possibility was suggested of dropping one such early strain for both seasons; and (3) the long duration type of rainfed or *pedda-panta* ragi gave good yields in the cool season under irrigated conditions and it was therefore suggested that a single strain might be used in these two seasons. In these experiments, strains AKP 1 and AKP 2 were found best in *punasa* season, AKP 6 for the *pyru* season and AKP 7 for the *pedda-panta* or main season crop.

Evaluation trials of different genetic strains were studied and reported by Peters, *et al.* (1969) in Uganda. Important characteristics of the higher grain yielding strains were: grain weight per head; medium maturity, flowering from 61 to 72 days after planting; broad or wide leaf blades which are erect or upright in growth; and head types with moderately curved or incurved fingers or spikes as a contrast to the very tight or open heads.

Seeding Experiments

Experiments on methods of seeding have been reported from Africa and the countries of Ethiopia (Debre Zeit, 1965), Kenya (Kenya Dir. of Agri., 1955), Zaire (Congo, L'INEAC, 1953; 1958), Malawi (Nyasaland-DA, 1959–60), and Rhodesia (Johnson, 1968). In Kenya, the yields of wimbi or finger millet were found to be reduced by ridging when grown at Nairobi in 1953 during the long rainy season. Close spacing studies in Zaire at the Nioka Station, Ituri, revealed that the best spacings and rates of sowing were in rows 30 cm apart and at the rate of 30 kg of seed per hectare. Later experiments suggested that even higher rates of sowing, up to 60 kg/hectare, were superior to lower rates of seeding. A factorial trial conducted at Baka, Karonga, in Malawi (Nyasaland) showed December sowings to be superior to February sowings; drilling an 18 in row on the flat was superior to broadcasting on the flat or sowing two rows of hills on ridges 3 ft apart.

Transplanting Experiments

There is a universal belief among experienced ragi growers that transplanting increases yields, reduces seed costs and results in generally better land use. Work at Bapatla, Andhra Pradesh, India (Rao and Raghavulu, 1964), involved comparing the transplanting of ragi versus direct sowing and different kinds of seeding in the two major seasons. Transplanting resulted in higher yields in two out of three years during the *kharif* or monsoon season. However, there was no marked advantage for transplanting over direct seeding in the *rabi* or winter season. July sowings were found best for the monsoon crop but it was found better to sow between the first and fifteenth of December than after December 31 for the *rabi* crop. The effect of transplantation on the ragi plant was studied in detail by Naidoo and Rao (1958). They compared direct sowing with a single transplanted and double transplanted crop of ragi. The single-transplanted treatments were grown from three-week-old seedlings, while the double-transplanted seedlings were moved from the first transplanted crop when it had become established two weeks after the transplantation. Although all treatments matured more or less simultaneously, the transplanted treatments gave considerable increases in number of tillers, total shoot length, number of roots per plant, total root length, dry weight of roots, number of laterals per inch of root and spread of roots. Number of tillers increased from 6 to 18 and 27, total shoot length from 56 to 170 and 258 in., dry weight of roots per plant from 6.3 gm to 19.05 gm and 30.6 gm, and number of laterals per inch of root from 7 to 20 and 52 for the control, single-transplanted and double-transplanted treatments, respectively. In other characters the single transplanting treatment was superior to double-transplanted and control treatments in number of roots per plant — 55 compared with 48 and 39, respectively; total root length per plant — 1,154.9 in compared with 908.8 in and 951 in, respectively; and lateral spread of roots — 52 in compared with 46 in and 20 in, respectively. However, the depth of rooting declined in the transplanting treatments compared with the control — 36 in. versus 26 in. and 22 in. for control, single-transplanted and double-transplanted treatments, respectively. Yields of grain per plant were 1,474.2 gm versus 3,088.2 gm and 5,046.3 gm for the control, single-transplanted and double-transplanted treatments, respectively; or 110% and 242% increases for the two treatments over the control. Similar increases were noted in yield of straw per plot which went from 18.6 kg to 24.9 and 30.4 kg per plot for the three treatments: control, single-transplanted and double-transplanted, respectively. It should be noted, however, that the studies were carried out on relatively widely spaced plants being 16 × 16 in between hills.

Age of Seedlings

The optimum seedling ages for transplanting varieties of ragi were studied by Divakaran and Sivagnanam (1960) and by Divakaran (1967). They found short duration and medium duration varieties like Co. 7 and Co. 2, respectively, are at the optimum seedling stage for transplanting between the 20th and 35th day; while long duration strains like Co. 1 are optimum between the 25th and 35th day. Beyond this optimum age, the internodes of the seedlings elongate and after transplanting, their growth and yields are poor. Old seedlings tended to produce more tillers but younger ones grew taller.

Clonal Propagation

The possibility of growing a short term ragi crop from tillers of profusely tillering cultivars like Nr. 124 was investigated over a six-year period in Orissa (Bhubaneshwar) by Mahapatra and Sinha (1965) and by Mahapatra (1965). They found clonal propagation of ragi produced plants with greater tillering capacity, later flowering (by 16–23 days), and considerably higher yields (2 to 3 times), than those from seedlings raised in the normal way. However, the response differed between varieties and the cultivar Nr. 124 was found to give the highest yield increase. They further postulated that the short term crop of only two-month duration could be taken between the period of harvesting rice and planting potatoes by resorting to this clonal propagation. Grain yields as high as 3,600 kg per hectare had been obtained by this method.

Irrigated Ragi

Investigations on time of sowing and plant populations in irrigated ragi in Chittoor district of Andhra Pradesh, India were reported by Rao, *et al.* (1965). They obtained highest fodder yields of 2,846 kg/acre from 25-day-old seedlings of the cultivar VZM 2 sown on January 9. In spacing populations studies carried out with Co. 7 seedlings transplanted after 25 days, they found the spacing of 6 × 9 in with 1 or 2 plants per hill superior to spacings of 6 × 6 in or 6 × 12 in in both grain and straw yields. In other investigations, Rao and Rao (1962) studied border effects in irrigated ragi. They obtained increases of border rows over central rows (12 in. row spacing) which amounted to 46.3% in weight of green earheads, 23.5% in weight of dry earheads, and 19.3% in grain yield in the improved cultivar VZM 2 (all significant differences). Other experiments on water use in irrigated ragi crops were conducted between 1943 and 1947 at Coimbatore, Tamil Nadu (Madras-DA, 1954). These indicated that a ragi crop of 122 days duration required from 23.3 to 33.9 acre inches of water. The best timing for irrigation was at weekly intervals and at the rate of three acre inches per irrigation.

Populations and Spacings

There is relatively little published work on population experiments in ragi. It is very likely that the high tillering capacity of the crop results in relatively small quantitative effects from comparatively large treatment differences. For example, early experiments on row spacings revealed insignificant differences between row spacings of 5, 10 or 12 in apart. Subsequent experiments carried out at Anakapalli, south India, showed that best yields were obtained when single seedlings were planted in spacings three-fourths of a link (8″) between plants in both directions (6 × 6 in). In another experiment conducted by Samathuvam (1961) at Coimbatore, Tamil Nadu, four improved cultivars of ragi, AKP 1, AKP 2, Co. 7 and E.C. 47?8, were compared in two different spacings and populations—6 × 6 in or 153,000 plants per acre, and 9 × 9 in or 100,000 plants per acre. The wider spacing was found definitely superior to the narrower spacing in grain yield giving increases of 11.9 to 39.9%; and from 3.1 to 18.8% in straw yields. Moreover, there was a marked increase in the number of tillers ranging from 2 to 4 in the closer spacing and 4 to 6 in the wider spacing. Therefore, the increased yield from the lower population was attributed to overcompensation in tillering in more widely spaced plants. Experience and investigations in central Africa, in both Uganda and Zaire, suggest that good yields can be obtained from row spacings of 30 to 33 cm apart with seeding rate of between 5.6 and 9 kg/ha. In fact, results from Ituri in Zaire suggest that seeding rates of 30 to 60 kg/ha gave better yields than lower rates of seeding (Congo, L'INEAC, 1958).

Fertilizers

There is a substantial amount of investigations recorded on fertilizer response in ragi. Most investigators have concluded that ragi gives an excellent response to fertilizers, but there is also a very high interaction between levels of the major nutrients and genotype and environment.

Factorial fertilizer trials, of nitrogen and phosphorus, showed significant increases of grain yield for both elements (Schumaker, *et al.*, 1969).

Organic and Green Manures

Early work on manurial experiments, both green and farmyard manure, were summarized by Coleman (1920). In a series of experiments conducted between 1910 and 1914 and from 1915 to 1918, it was concluded that green manure crops like cowpeas and sunhemp could increase yields of ragi as much as 6 to 10 cartloads (3–5 tons) of cattle manure. He also concluded that sunhemp and cowpeas were the best green manures and were more profitable to use than cattle manures. In the first series of experiments, the increases from green manuring with sunhemp was 39% over the control, while cattle manure and cowpeas (enriched with potassium sulphate and basic slag) increased yields by 35% and 31%, respectively. In the second series of experiments, increased yields ranged from 25 to 31% over the control with cowpea green manure giving the maximum increase. The same treatments applied to early or Kar ragi during 1910 to 1915 were somewhat less promising resulting in increases of only 11 to 17%. Other experiments carried out in Tamil Nadu showed no marked difference in the effect of different forms of organic manure, but it was discovered that farmyard manure, sufficient to supply 75 lb of nitrogen, was clearly superior to the quantity of farmyard manure required to supply only 50 lb of N per acre (Madras-DA, 1954). Green manures were also shown to have an effect on utilization of phosphorus by ragi in experiments by Venkatrao and Govindarajan (1960). They showed that yields and utilization of both nitrogen and soil phosphorus by ragi were increased by the application of 5,000 lb/acre of *Glyricidia maculata* leaves as green manure three weeks before planting and 0.5 cwt/acre of superphosphate at the time of planting.

The results of manurial experiments in both organic and inorganic forms in Tamil Nadu was reviewed by Rao (1952) and later by Mariakulandai and Morachan (1966). They concluded that continuous manuring of millets gives good response, increasing the yields of both grain and straw. Phosphates were found to be an essential supplement to nitrogen for most millets and maximum benefit will only be obtained with the appropriate mixtures of these two elements. Among the several sources of nitrogen, ammonium sulphate was found best for millet. In the case of dryland crops there may be a depression in yield following the application of inorganic nitrogen if rainfall is not normal and adequate. The most economic doses of the major nutrients are 30 units each of N and phosphoric acid on dry land and 50% higher levels under irrigated conditions in Tamil Nadu.

Mixing Organic and Inorganic Fertilizers

Many of the fertilizer experiments on ragi have involved superimposing different levels of the major nutrients over a basic organic manurial source such as farmyard manure or compost. Narasimhamurthy and Rao (1961) compared performance with and without farmyard manure supplemented by 45 lb of nitrogen, 45 lb N, plus 20 lb P_2O_5 and 45 lb of N, plus 20 lb P_2O_5, plus 45 lb K_2O

and no chemical fertilizer. They obtained no significant response to farmyard manure and concluded that the most economic treatment was of 45 lb of N given as ammonium sulphate. It was therefore concluded that 3 tons of farmyard manure which is the usual practice for *pyru* ragi (the cool season crop) was totally inadequate as a commercial practice. In other experiments carried out at Delhi by Walunjkar and Acharya (1955), comparison was made of composted manure with an equivalent level of P_2O_5 from superphosphate alone. They found the composted manure giving a better response than the superphosphate application probably as a result of the nitrogen in the compost; and they also observed that superphosphate applied to cattleshed waste and composted for four months was more effective than compost and superphosphate applied separately. In similar experiments, Rao and Govindarajan (1956) studied the mixing of phosphate and farmyard manure together before application versus applying them separately. They found that mixing or composting the superphosphate with farmyard manure resulted in appreciable increase in yields of ragi grain and straw and that the total amount of P_2O_5 recovered by the crop was increased considerably, indicating better and more efficient utilization of the added phosphate. The response of ragi to farmyard manure and different rates of N, P and K were studied in experiments for five years at Bhavanisagar, Tamil Nadu by Ananthapadmanabhan, *et al.* (1967). They found that when 10 tons of farmyard manure were applied as a basal dressing there was no response to P or K, but that 60 kg of N applied in split doses at sowing and as a later top dressing increased the average grain yields by about 50% to 953 kg/ha.

Compost Sources

Pot culture experiments with ragi and sorghum on red loam soil to compare different forms and sources of compost were carried out by Acharya, *et al.* (1946). The following compost produced yield responses in descending order of effectiveness:

1. Ash powdered from night-soil (city compost) and wood ash,
2. Compost from night-soil and town refuse,
3. Farmyard manure,
4. Compost from mixed farm refuse, and
5. Ammonium sulphate.

All of the organic forms of manure were found to leave a significant residual effect in the soil. When uncomposted mixed refuse was applied, it produced a depressing effect on crop growth at carbon: nitrogen ratios wider than 50 : 1. However, significant yield increases were obtained at carbon: nitrogen levels of 30 : 1 and narrower. The harmful effect of the wider C:N ratio compost could be neutralized by adding nitrogen at the rate of 0.75% to the dry matter of the trash. When the amount of nitrogen was increased to 1% of dry weight of trash, a significant increase in crop yield over untreated soil was obtained. Moreover, this increase was superior to the same quantity of nitrogen applied as ammonium sulphate alone. A similar effect was obtained by adding oilseed cake at the rate of 0.5% N to the dry weight of trash (sugarcane trash). The superiority of oilseed cake at a lower nitrogen level is attributed to the phosphoric acid contained in it.

Fertilizer Use in Africa

There is relatively little information on finger millet fertilizer experiments in Africa. In Uganda a report of work done at Serere in 1952 indicated that ragi responded to lime applications at the rate of two tons per acre and to farmyard manure (Uganda-DA, 1953). However, in Malawi (Nyasaland) applications of kraal manure to finger millet increased yields by 400% at Zomba in 1950 (Nyasaland-DA, 1952). Similar experiments carried out at Lusaka Zambia (Northern Rhodesia) in 1954, resulted in yields of 8, 2.5 and 1.75 bags (200 lb) of grain per acre from manurial treatment of 12.4 and 0 tons of farmyard manure (Rhodesia-DA, 1955).

Major Nutrient Response

Nitrogen alone.--The most frequent major nutrient assumed to be lacking in ragi cultivation is nitrogen. Therefore, a considerable amount of experimentation has been done at different levels of nitrogen alone or superimposing nitrogen levels on standard basal dressings of organic manure and/or the other two major nutrients, phosphorus and potash. Frequently, nitrogen alone has given good response whether or not basal applications of other nutrients have been made. Narasimhamurthy, *et al.* (1960) conducted manurial experiments on ragi over a three-year period at the Millet Farm, Vizianagaram, India, from 1956–57 to 1958–59. They found that the application of 20 lb of N as ammonium sulphate was the best and most economic fertilizer level to use. Application of super-phosphate produced no extra increases in yield. In other studies, Narasimhamurthy (1952) obtained yield increases from applications of nitrogen up to 50 lb/acre, but found the most profitable level to be 40 lb under the conditions studied. Investigations on very early ragi maturing within 85–88 days from sowing, during May to August, were carried out by Venkatanadhachary, *et al.* (1966). They supplied plant nutrients in the form of ammonium sulphate alone, ammonium sulphate plus superphosphate and ammophos. They found that applications of nitrogen alone significantly increased grain yield, while phosphate applications did not influence grain yields in any way. They obtained good response in grain yields of up to 2,838 kg/ha from nitrogen levels as high as 89.7 kg/ha compared with yields of 2,142 kg/ha when 44.8 kg/ha of nitrogen were applied. This is the level of nitrogen fertilizer apparently being recommended in Tamil Nadu. Ragi growers along the east coast of Andhra Pradesh, do not ordinarily fertilize their crops. However, work done by Rao and Ramchandra Rao (1963) showed that yields of grain were almost doubled by inorganic manures versus no manure and that applications of 45 units of nitrogen increased yields substantially. Nevertheless, phosphorus and potash did not produce any response under those conditions during the monsoon season of August to December. As a consequence of these results further applications of nitrogen are recommended. The first to be given at transplanting and the second one month later in this region. Reports from other countries indicate similar response from applications of nitrogen. The Marandellas Grassland Research Station (1956–57) obtained grain yield increases of nearly 3% when ammonium sulphate was applied at 300 lb/acre but no further response was obtained from heavier dressing; nor was there any effect from seed rate (8 and 16 lb/acre) or application of phosphorus. Response to nitrogen is also recognized in East Africa, where 125 kg/ha of sulphate of ammonia are recommended as a broadcast application when the crop is about 15 cm high and after weeding. This has been shown to increase grain yields by about 450 kg/ha (Dunbar, 1969).

Azotobacter in the Root Zone

The possible role of azotobacter in the root zone of ragi and other crops contributing to the total nitrogen supply was investigated by Sundara Rao, *et al.* (1963), and Moore (1963). In the former experiments carried out at New Delhi, India, azotobacter was supplied as a source of culture to *Eleusine coracana*, and increased yields were obtained in pots but not in the fields. In Moore's experiments the nitrogen contents of four latosolic soils having a total N content of 0.05 to 0.098% and organic matter content of 0.95 to 0.56% did not change when the soils were kept moist in a greenhouse for four months. However, when *Centrosema pubescens* and *Eleusine coracana* were grown, increases of nitrogen in the soil/plant system for a 6 in depth over an acre were, respectively, 100 to 200 lb and 100 to 130 lb. These changes were postulated to have occurred from non-symbiotic fixation and both azotobacter and Beijerinckia were recovered in the sampling process. The author, therefore, had prophesised the importance of non-symbiotic nitrogen fixation in the humid tropics.

Balancing of Elements

Although many experiments have demonstrated no appreciable response from the other two nutrients, phosphorus and potash, considerable other evidence suggests that ragi does in fact respond to both elements. Moreover, much of the experimentation that has been carried out has been superimposed over a basal application of farmyard manure or other organic type compost. The residual effects of applying these two elements to previous crops have not been considered. The response of dryland ragi to applications of 30 lb of nitrogen and 15 lb of phosphorus per acre was studied in an extensive series of 343 demonstrations in Karnataka (Mysore-DA, 1965). Grain yields were increased by 200 to 400 lb/acre and straw yields were increased by 52 to 98% on the average. The increase in straw alone (a by-product used as fodder) was sufficient to pay the cost of the fertilizers. In a similar set of 10 demonstrations with very high levels of fertilizers, 120 lb of N and 30 lb of P_2O_5 per acre, conducted in 1964, it was conclusively shown that there was no burning effect of the fertilizers on dryland ragi when grain yields ranged from 50 to more than 400% above the control. Other experiments carried out at Hyderabad on sandy, infertile soil involved treatment combinations of nitrogen, P_2O_5 and K_2O each at 45 lb/acre together with farmyard manure, green manure and compost again applied at rates equivalent to 45 lb of nitrogen (Venkataramana and Krishnarao, 1961). Growth and yield were better if the basal dressing of farmyard manure preceded the fertilizer treatments, but nitrogen, phosphorus and potash in combination gave the best yields. Grain yields were proportional to the uptake of nutrients and the percent of dry matter increased up to the flowering stage of the crop, but nitrogen content declined as the plant approached maturity. The nutrients removed by ragi in producing 1,000 lb of grain and 4,000 lb of straw were calculated at 21 lb of nitrogen, 15 lb of P_2O_5 and 20 lb of K_2O. Similar results were obtained by Rao and Govindarajan (1956) who obtained increased grain yields and ratios of straw to grain where higher levels of phosphorus and nitrogen fertilizers were in balance. However, they found less recovery of nutrients in ragi than in rice.

Genotype and Plant Development

The possible interactions of genotype with nitrogen for fertility levels has not been extensively studied. Shetty and Mariakulandai (1964) tested nitrogen levels on three short-duration varieties including AKP 2, E.C. 4728 and Co. 7. Of these, Co. 7 was the highest yielder followed by E.C. 4728 and AKP 2 in Tamil Nadu. Similarly, increased nitrogen levels favored Co. 7 most and then E.C. 4728. The indirect effect of nitrogen fertilizer on the components of yield in ragi was studied by Krishnamurthi (1967). He found that numbers of tillers and ears per plant were linearly related to rate of nitrogen up to 89.9 kg/ha, and an increase in the nitrogen rate increased the number of early and intermediate tillers more than that of late tillers. In the same cultivar, H-22, the contributions of tillering to total ear numbers per plant were 15% from the main axis and 40%, 21% 14% and 10%, for early, intermediate, late and secondary tillers, respectively.

Source of Nitrogen

The source of nitrogen for most cereal crops has seldom been found consequential in affecting plant development and performance. In

India, Sinha (1956) obtained equal results with ammonium chloride and ammonium sulphate at the lower or 20 lb nitrogen level, but at the higher level of nitrogen tried, i.e. 50 lb of nitrogen per acre, ammonium sulphate was superior to ammonium chloride, particularly in combination with 40 lb of P_2O_5 and 20 lb of K_2O. In laterite soils ammonium sulphate was found superior to ammonium chloride at both the 25 and 50 lb levels, but on old alluvial soils 25 lb of nitrogen as ammonium chloride was better than ammonium sulphate at the same level although at the 50 lb level ammonium sulphate was superior. In other experiments, Pillai and Purushothaman (1958) did not attain statistically significant differences between ammonium nitrate and Chilean nitrate of soda applied at levels of 40 and 60 lb of nitrogen per acre. In Tamil Nadu, three sources of nitrogen applied to ragi were compared by Iruthnayaraj and Rajarathnan (1965). They obtained responses of up to 33% in grain and 40.6% in straw over the unfertilized control, but they did not demonstrate any statistical difference of one source of nitrogen over the other. They, therefore, concluded that calcium ammonium nitrate is as efficient as ammonium sulphate and urea in increasing grain yield in ragi. They also established that 40 lb of nitrogen was the most economic optimum.

The response of finger millet to nitrogen application in the Sudan was studied by Willimott and Anthony (1958) at the Yambio Experiment Station. In preliminary studies, carried out on dark sandy loam underlain by a sandy clay, they tried ammonium sulphate and sodium nitrate at rates of 38 and 76 lb per acre of nitrogen. Only the ammonium sulphate at the higher rate markedly increased yields which were 40% higher than those obtained with equivalent amounts of sodium nitrate. The investigators suggested as explanation, the possible preference of ragi for nitrogen in ammonia form or the supplementary effect of sulphur and to the unavailability of nutrients owing to a temporary increase in pH by the sodium nitrate.

Phosphorus Effects

The role of phosphorus in cereal nutrition is often thought of as supplementary to that of nitrogen. However, some experiments have shown a definite response to increasing levels of phosphorus. In preliminary experiments with ragi in Karnataka, Rao and Govindarajan (1956) obtained increased yields with applications of P_2O_5 up to 80 lb per acre at a constant level of 40 lb of nitrogen per acre. Moreover, the recovery of nitrogen in the crop steadily increased with increasing levels of P_2O_5. In studies of the form of fertilizer phosphorus, Datta and Dev (1963) found that ragi utilized soil phosphorus in preference to fertilizer phosphorus. They also established that source of phosphorus made no difference whether from dicalcium phosphate or superphosphate. Source of phosphorus was also studied by Ramulu and Mariakulandai (1962) in Tamil Nadu. Phosphorus was supplied in the form of farmyard manure and superphosphate individually and in combinations ranging from 1–1 to 1–3. Combinations of the two sources yielded higher amounts of available phosphorus than individual applications of either source. However, superphosphate was preferable to manure when each was supplied individually.

Methods of applying phosphate fertilizers to ragi in order to make this element more available was studied in a series of plot experiments at Delhi by Das (1945). Superphosphate was applied at different depths to a calcareous Pusa soil with supplementary nitrogen added. Maximum production was obtained in plots where the phosphorus was placed 4–5 in beneath the surface. After harvest, soil borings at different depths, up to 16 in, were examined for total phosphate contents and it was found that P_2O_5 did not reach downward beyond 4 in. from the depth of application, but tended to remain within the 4 in. volume in the soil.

Potash Effects

The beneficial effects of potash fertilizers is seldom demonstrated particularly in the presence of organic manures. A report by the Indian Academy of Agricultural Scientists (1965) on studies of the response of Co. 7 ragi to phosphatic and potassic fertilizers in Tamil Nadu revealed that there was no response to additional applications of phosphate and potash over basal dressing of 5 tons of farmyard manure and 60 lb of nitrogen. Moreover, it was shown that there was no comparative advantage of liquids to solid fertilizers. However, in other experiments, Rao and Sirur (1958) showed fair response in ragi yields to the application of potassium in both field and greenhouse, except in one soil having an acid reaction. In other plot experiments, Rajagopal and Iyengar (1938) studied dry matter, ash, phosphorus, potash and pH in plant sap from different combinations of fertilizer treatments. They found the potash treatments increased the solids in the juices but did not give consistent or striking increases in potash concentration. The reverse was true in the case of nitrogen and phosphate treatments where the plant sap was higher in both elements following the respective treatments. However, the unfertilized control was standard and the sap contained more dry matter, ash, phosphorus, and potash as well as seemed more alkaline than the fertilized plants.

Foliar Nutrition

Application of major nutrients through foliar spraying of ragi and maize was investigated by Narayanan and Vasudevan (1959) in Tamil Nadu, India. They tried urea, ammonium sulphate, potassium sulphate, copper sulphate, and manganese sulphate. These were applied in a 0.5% solution at the rate of 100 gallons/acre. Plant height was increased for maize but not in ragi. Grain yields were also increased to a greater extent in maize than in ragi, but increases in straw weight were less. A single application of urea at 0.5% on ragi increased grain yield by 5.3% and straw yield by 9.9%; two sprayings increased yields by 8.2 and 11.2%, respectively. Magnesium sulphate sprayings increased straw yields by 11.2% and grain yields by 4%. Copper sulphate, manganese sulphate and potassium nitrate sprays also gave positive responses. Adding sucrose to the urea had no advantage over urea alone, but among the nutrients tested, urea was the most consistently satisfactory.

The effect of foliar nutrient sprays on rhizosphere microflora of *Eleusine coracana* was investigated by Bagyari and Rangaswami (1967). They treated 15 to 90-day-old ragi plants with nitrogen, phosphorus and potash at 0.350 M, 0.324 M and 0.256 M, respectively. Bacteria population in the rhizosphere was increased by the nitrogen and suppressed by phosphorus and potash. However, actinomycetes were increased by both nitrogen and potash. The researchers concluded that foliar nutrients and particularly nitrogen tended to increase the population of fungi but decreased that of *Azotobacter*.

Mineral Content of the Plant

The uptake and retention of the three major nutrients and calcium by ragi grain and straw following application of fertilizers was studied in Tamil Nadu by Ramulu (1964). He found superphosphate was more effective in raising the phosphorus content of the grain in straw than farmyard manure on an equal phosphorus basis. Moreover, increasing the amounts of farmyard manure had a depressing effect on the phosphorus content of the straw, while the application of phosphates tended to increase both potash and nitrogen content but decreased the calcium content of the grain. However, the potash content of the plants appeared inversely related to the calcium content of the plant. Uptake of calcium during the growth of short-duration ragi was found to be maximum when the plants were approximately one month of age, but declined until flowering time and then increased slightly until harvest. This was not true in the case of long duration ragi where there was a gradual decrease of calcium content of the straw from the first month to harvest time. The calcium content of the straw was observed highest in plots receiving heavier applications of farmyard manure.

The nitrogen content of the grain was increased by manuring. Applications of phosphorus as a combination of both organic and inorganic forms produced a higher nitrogen content in the grain than treatments of either one alone. The combination of low farmyard manure and high superphosphate application was superior to the combination of high farmyard manure and low superphosphate in raising the nitrogen content of the grain.

The effect of fertilization on nutritive values of ragi grain was studied by Ramiah (1933). He found that rabbits fed on ragi seedlings growing on soil fertilized with cattle manure increased 25% in live-weight compared with only 29% for animals fed on plants fertilized with inorganic compounds or receiving no fertilizer. The coefficient of digestibility of the nitrogen in the plants for the unfertilized plants was 61.8%; for those fertilized with inorganic compounds 69.9% and for those fertilized with cattle manure 74.0%. In work with other cereals he concluded that cattle manure depressed the nitrogen content of plants, whereas ammonium sulphate applications increased the nitrogen content of forage plants. He also found the prolamin content of ragi grain to be highest in unfertilized plants, followed in order by those receiving inorganic compounds and cattle manure, respectively. There was a rough correlation between the total nitrogen and prolamin contents.

Minor Nutrients

Very limited work has been done on the response of ragi to minor nutrients. Most of these investigations have been concentrated on zinc, copper, iron and manganese on soils in south India.

Zinc.—The effects on ragi of boron, copper, zinc and combinations of them were studied at Bangalore in south India by Gopalarao and Govindarajan (1950), and by Govindarajan and Gopalarao (1964). The best response was obtained from zinc. This element was applied at the rate of 5 lb zinc sulphate per acre on Bangalore soils. It resulted in increases of 23% in yields of dry grains and straw. Later experiments showed that seed treatment with solutions of zinc sulphate would give near similar increases in crop yields under both dry and irrigated conditions. Applications as low as 1% of zinc salt in respect of the weight of seed was found effective (Govindarajan, 1953).

Copper.—Investigations on response to copper were done in Tamil Nadu by Gopalkrishnan (1960a, 1960b). He applied copper at 0, 10, 20, 50 and 100 parts per million at seed germination. Data was taken on plant height, leaf area, time of flowering, dry matter production, chemical composition at different stages of growth and yields of grain, straw and roots in sorghum and two millets. The optimum concentrations of copper in the growing medium for these species were sorghum 20 parts/million, *Eleusine coracana* 50 parts/million and *Pennisetum typhoides* 50 parts/million. In chemical analyses of the leaves and plant parts of these millets, the positive effect of copper nutrition on the intake of nitrogen, phosphorus, potassium, calcium, magnesium and iron and on the content of reducing sugars was clearly shown.

Iron and manganese.—Experiments with manganese and iron applied as potassium manganate and ferric oxide were conducted by Harihara Iyer and Rajagopalan (1939). They confirmed a positive response in ragi and tomato and they also showed that these oxidizers would remain in the soil in the acid soluble condition for long periods.

Effects of Soil Salinity

The effects of soil salinity on germination, early vigor, crop duration and grain setting in ragi were studied in south India by Kaliappan, *et al.* (1967) and Kaliappan and Rajagopal (1968). They found chloride salinity of 2,000–4,000 parts/million in red loam soils with a pH of 7.6 reduced both the germination and the shoot height of 10-day-old seedlings of three ragi varieties. Of these, the cultivar Co. 7 was more tolerant of salinity than either Co. 8 or ECW 840. Yields were least affected in Co. 7 and Co. 8 and panicle emergence was least delayed in Co. 7. ECW 840 was much more sensitive to salinity in experiments at Coimbatore, India.

Chemical Weed Control

There is a considerable dearth of knowledge concerning the feasibility of chemical weed control in ragi. The use of chemicals is hardly ever advocated in recommendations put out by departments of agriculture in ragi growing regions. A brief report on comparing the use of Fernozone with that of Hedonal and hand weeding was reported by Naidu and Singh (1958). In these studies, Fernozone was found more efficacious in the control of weeds in ragi than Hedonal (M). Grain yields were highest from hand weeded plots than from Hedonal (M) and lowest from Fernozone treated plots. These results imply that the Fernozone, although more effective in weed control, was also more damaging to growth and development of ragi.

Conclusions on Agronomical Investigations

The majority of the management investigations on *Eleusine coracana* have been carried out in Karnataka and Tamil Nadu in India and to a lesser extent, in Maharashtra and Andhra Pradesh. There are relatively few reports of investigations from the other important ragi-growing regions like East and South Africa. Generally, the quantity of work on this crop can be considered minimal and much of it is contradictory. It appears that many investigations have been done under conditions where one or more factors other than those being observed and tested are limiting to crop growth and development. For example, when response to nitrogen is being tested, the limitations of factors like diseases, insects, lodging, or unavailability of adequate moisture may not have been considered or reported. In most of the nitrogen fertilizer level experiments, the increments of application often appeared to be relatively low, that is, N level may be applied by ten unit increments up to not more than 60 units, whereas the highest level should be at least double or triple this quantity.

It appears that fertilizer responsive genotypes have not been conscientiously searched for and sorted out. The only conscious effort to identify fertility responsive genotypes was made by the All India Coordinated Ragi Improvement Project at Bangalore in 1965. The World Collection of *Eleusine coracana* consisting of about 1,000 entries was grown in the summer season at the University of Agricultural Sciences at Hebbal, near Bangalore. Two levels of nitrogen fertility were used in two sets of plantings made at the end of January. The low level consisted of 90 units of nitrogen and the high level consisted of 150 units of nitrogen in split applications. Plots were small, consisting of only one row about 3 m in length and 45 cm between plots. Every attempt was made to supply adequate irrigation, insect pests were kept under reasonable control and there were no apparent serious infestations. The important agronomical characters were recorded and catalogued and yields were taken on a 1 m sample. The results were highly gratifying in that several dozen genotypes exceeded the equivalent of 5,000 kg/ha of grain yield and at least six entries yielded an excess of 7,000 kg/ha.

The response to other major nutrients, specifically phosphorus and potash, has not been conclusive under different conditions where ragi is grown. Moreover, responses have been observed and measured often at relatively low yield levels. It is suggested that responses to phosphorus and potash may be quite different when current experimental yield levels of 1,000 to 2,000 kg/ha are doubled and tripled. Certainly, the responses to the major nutrients cannot be effectively evaluated if treatments are superimposed over a basal application of farmyard manure or other organic materials unless these materials are properly analyzed for both their total and available nutrient contents.

The problems of minor nutrient deficiencies and response have not been adequately investigated for different conditions and genotypes. Among these positive response has been most clearly shown with zinc in Karnataka. It is suggested that this element should be tried in other regions where this crop is important.

Another aspect almost completely neglected is that of weed control in ragi. The crop as presently cultivated requires a very considerable amount of hand labor for weeding and interculture. Much of this work is done by the family including children who are increasingly attending school as educational standards rise. Thus it would seem likely that several of the excellent new selective herbicides might work in helping control the important weed pests occurring in ragi crops.

PLANT PROTECTION

Diseases

Early investigators and observers of *Eleusine coracana* had a common belief that diseases of ragi are relatively unimportant (Coleman, 1920; Venkatakrishnaiya, 1935; Patel, 1955). Moreover, these early workers considered *Helminthosporium* species to be more important than other pathogens. More recently, blast has been considered extremely important owing to the high losses that can occur from certain types of infection, particularly when the neck and lower earhead are affected. More recent literature indicates a considerable number of different pathogenic fungi can infect and cause loss to *Eleusine coracana*. There are at least 14 fungal pathogens in addition to blast and two species of *Helminthosporium* that have been reported infective on ragi. It is also susceptible to at least one bacterial disease and two or three virus diseases causing a mosaic or mottling of the leaves, a freckled yellow, and chlorotic symptoms like maize streak. Moreover, in regions where it occurs, the phanerogramic parasite *Striga asiatica*, and *Striga densiflora* have been reported to infest ragi plants.

There are several good reviews on ragi diseases including Venkatanarayan (1947) and Misra (1959). However, a more recent and considerably more comprehensive study of millet diseases is available from the Indian Council of Agricultural Research (Ramakrishnan, 1963).

Blast (*Pyricularia* sp.)

Blast has been recorded to infect ragi throughout most of its growing region, namely central and south India, Sri Lanka, Malaysia, Japan and East Africa. However, it has been studied more extensively in India and Japan than elsewhere. McRae (1922) reported that blast may occur on ragi in epidemic proportions and that loss of grain yield may exceed 50% in some years. In Coimbatore district of south India the crop may be completely destroyed under certain conditions and yield losses of 80 to 90% have been reported from the adjoining state of Karnataka. It is quite common in Uganda, and was particularly severe in very wet years such as 1961 and 1962 (Dunbar, 1969).

Symptoms.—The symptoms of blast on ragi are very similar to those that appear on rice. Large oval or elongated brown spots occur on the leaves and often the neck below the earhead is attacked, resulting in failure of grain set or shrivelled seeds. The fungus also occurs on the head itself causing improperly filled grains or heavily blasted florets in the sections attacked.

Blast affects ragi in all stages of growth from the seedling to the time of grain formation. Spindle shaped lesions of varying sizes are formed on seedling leaves. These are usually greyish-green in the center with a yellowish margin, but later the central portion turns whitish and gradually disintegrates. Under humid conditions, hollowed grey growth of the fungus may cover the central portions of the lesions, particularly on the upper surfaces of the leaves. This overgrowth consists of the conidiophores and the conidia of the fungus. In the early stages of the infection, the lesions are isolated but often quickly coalesce and cover extensive areas. The distant portions of leaves beyond the lesions may dry up, break over and drop off. Infection in the mature plant is very similar to that of the seedling stage. Lesions may measure 1–2 cm in length and 0.3–0.5 cm in width. However, the greatest damage occurs when the plant becomes infected at the heading stage. Often the upper peduncle immediately below the head becomes infected over an area of 3.0–5.0 cm and individual portions of the head or fingers can be infected and break away from the stalk. These infected areas become discolored and shrunken. A hollowed grey fungus growth covers the area. Grain formation may be inhibited completely or the developed grains will be shrivelled. Sometimes the upper nodes of infected shoots become black as in rice blast. Loss in yields depends more on the time of infection than on those affected in the early stages of growth (Ramakrishnan, L.C.).

Pathogen.—The causal organism for ragi blast has not yet been fully identified. The epithet *Pyricularia eleusinus* has been used but without authoritative backing. In Sri Lanka, *Pyricularia crusea* has been recorded on ragi (Park, 1932); while in Uganda, Hansford (1943), and, in Tanzania, Wallace and Wallace (1948), identified the pathogen as *P. oryzae*. In India Ramakrishnan (1948) considered the fungus to be a race of *P. oryzae*, since he could find no obvious differences between the two organisms. However, Wallace (1950) concluded that the pathogen, although morphologically very similar to *P. oryzae*, was a different species and that it would be classified as *P. setariae*; while Thirumalachar and Mishra (1954) identified the causal organism as *P. grisea*.

The morphology and physiology of *Pyricularia* sp. causing ragi blast was studied by Thomas (1940). He observed that the fungus grew best in culture medium between pH 5.0 and 6.4. The optimum growth temperature was about 29.5° C, but there were no appreciable differences in growth between 20° and 30°C. The minimum and maximum temperatures at which the fungus was able to grow was 5° and 36°C, respectively, and the thermal death point of the conidia was reached between 48° and 49°C.

The morphological structure of *Pyricularia* has been described by Ramakrishnan (L.C.) as follows: hyphae—septate and hyaline when young, turn brownish and may be swollen when older; length of cells vary between 1.5 and 6.0 microns. Conidiophores—emerge through the stomata or epidermal cells; are simple, septate and dark-colored at the base and lighter above. Conidia—obpyriform shape and sub-hyaline. Spores—formed acrogenously, one after another by the sympodio growth of the conidiophore; each three-celled, the middle cell being broader and darker than the others; vary in size from 19–31 microns by 10–15 microns. Chlamydospores—globose, thick-walled, olive brown or dark brown in color, 4 to 10 microns in diameter; may be terminal or intercallary and may also be produced at the end of germ tubes.

Infection.—Cross infectivity experiments have been carried out by several workers. Thomas (1940, 1941) found that the ragi strain of *Pyricularia* fails to infect rice and ginger but does infect wheat, barley and oats quite readily. He also found that strains from rice and *Panicum repens* would infect only its own host, and the strains from ragi and *Setaria italica* were capable of infecting wounded leaves of each other but would not infect rice or *Panicum repens*. Ramakrishnan (L.C.) also reports that the ragi pathogen readily infects bulrush millet, maize and *Dactyloctenium aegyptium* but would not infect rice and *Digitaria marginata*.

Environmental conditions have been shown to have considerable influence on the intensity of blast infection. In south India the incidence of diseases is particularly severe from October to December, which are the principal rainy months. In this same environment, ragi sown during the hot dry summer, January to April, usually has no infection (Thomas, L.C.).

Studies on the nature of infection have shown that seedlings are more susceptible to leaf blast than mature plants. However, no relationship has been shown between the intensity of seedling infection and that of later ear infection. Rather, the prevailing weather conditions at a particular stage of crop development determine the intensity of blast infection. Survival of the fungus from season to season is through its persistence on alternate hosts and on plant debris and stubs left in the field or the straw preserved for fodder. The seeds have been shown to carry the infection particularly on shrivelled seeds of previously infected plants.

Varietal Reaction.—Varietal resistance to ragi blast has apparently not been studied very thoroughly since very few strains have been identified as carrying even moderate levels of resistance. Work at Coimbatore in India showed that the strain E.C. 155 possessed medium resistance in the early years of testing, but in later seasons it was found to become susceptible. Another cultigen, R-6, was found to have field resistance at Kovilpatti but proved susceptible at Coimbatore in the same state. More recently, a new strain, K-3, was found resistant in Coimbatore (Ramakrishnan, L.C.). In East Africa, the strain Mozambique 359 was mentioned as a source of resistance to *Pyricularia orisi* in a program to transfer its resistance to local Uganda strain (Uganda-DA, 1958). A general observation reported by Krishna Rao (1947–48) stated that the pigmented types of ragi are more resistant to blast than the non-pigmented ones. Inheritance of the purple pigmentation is dominant over green.

Chemical Control.—Several fungicides have been shown effective in controlling blast disease in the seedling stage of plant development. In Tamil Nadu, it was shown that the nursery could be protected by spraying a 1% Bordeaux mixture, and that spread of the disease could be further reduced by clipping the tips of infected leaves and by dipping the shoots in Bordeaux mixture during transplanting of the crop. However, dusting with sulphur or spraying ears with Bordeaux mixture did not help in controlling the infection (Madras-DA, 1954).

Experiments with several fungicides in an attempt to control blast were reported from different locations in south India. At Bapatla in Andhra Pradesh, the best fungicide tested for blast control included Bordeaux mixture 1% and 50%, copper oxychloride at 0.47% concentration (Raju and Rao, 1961). At Coimbatore among 15 fungicides tested on ragi, a Ceresan/lime mixture dust, Dithane Z 78, Flit 406, Bordeaux mixture, 1% wettable sulphur, Firbam, and Ziram were found to reduce the incidence of blast and also increase grain yield to a significant extent (Shanmugam *et al.*, 1962). In the same state at Tindivanam, Vijayan and Natarajan (1967) reduced leaf infestation by *Pyricularia setariae* to 43–55% compared with 67% for the control by spraying fungicides. Of the nine tested, the Ceresan/lime mixture gave the highest disease control and increased grain yields by 20.5%.

Seed treatment with fungicides or a combination of fungicides and insecticides should not affect germinability or subsequent growth of a crop even if not required to control pathogens or pests. Channama and Delvi (1966) showed that treatment of ragi seeds with Agrosan G.N. and Yellow Cuprocide did not at all affect germination or subsequent seedling growth but rather improved emergence of the young seedling.

Blight and Rots (*Cochliobolus nodulosus* Luttrell)

Leaf and seedling blight and fruit rot was previously known as *Helminthosporium nodulosum* Berk. and Curt., and it is sometimes found in association with a very similar but less virulent pathogen *Helminthosporium leucostylum* Drechsler. It has been reported widespread in India and in several other countries including the Philippines, Japan and the United States and also in Africa. It attacks other species of Eleusine besides ragi, including *E.indica* and *E.aegyptica* (Butler, 1918; Madras-DA, 1954; Coleman, 1920; and Venkatakrishnaiya, 1935).

Symptoms. The disease may occur sporadically in the field or in well-defined patches. It affects all parts of the plant including the roots, the stems, leaf sheath, leaf blade, spikes and spikelets. Germinating seeds may be killed before the seedling emerges above the soil. In developing seedlings lesions are small, oval in shape and light brown in color. These soon became elongated up to 1 cm in length and 1 mm in width and tend to coalesce forming patches of stripes that later turn dark brown in color. Infected leaves wither prematurely and seedlings may die within two weeks of infection. Mitra and Mehta (1934b) found the fungus affects roots and the base of the stems resulting in root rot and fruit rot with consequent rapid death of infected plants.

Lesions are formed on the leaf blade and leaf sheath of older plants. The spots on the leaf sheath are now well-defined and are usually located at the junction of the blade and the sheath. Stem lesions are frequently oblong and sepia colored. The fungus also attacks the upper peduncle and the head. Once the tissues are infected, necrosis sets in, the tissues collapse and portions above the lesions or point of infection usually die. This results in breaking and dropping away of leaf tips, spikelets, fingers and even the entire head. Grains are often poorly developed or shrivelled and there can be considerable reduction in yields (Ramakrishnan, L.C.).

Pathogens. Detailed studies of ragi blight were made by Mitra and Mehta (1934a) who found that two fungi were involved, *Helminthosporium nodulosum* and *H.leucostylum.* The latter was less harmful to the host, infecting only the leaves (causing shredding) and the ears. In later investigations, Luttrell (1957) decided that the two species were identical, representing different growth forms of the same fungus, and field isolates were almost equally divided into the two reaction groups. Luttrell (1956) also observed the perithecial stage to be nearly identical with *Cochiobolus kusanoi* Nisikado. However, the conidial stages were distinct from those of C.kusanoi and the perfect stage of *H.nodulosum* was described in 1957 as a new species, *Cochliobolus nodulosus.*

The fungus *C.nodulosus* is characterized by erect or curved unbranched conidiophores profusely formed in the central portions of the lesions. They may emerge either through the stomata or directly through epidermal cells. The size varies from 80 to 250 microns in length and 5 to 7 microns in width. Those formed on the ears are often larger or longer than those on the leaves, the latter having bulbous space and averaging 151 microns by 6 microns. Up to 18 septa may be formed, the color changing with age, being hyaline at first and then turning dark brown at the base, paler at the apex.

The conidia are borne at the tip of the geniculated conidia singly and one after another. Up to 11 spores may be formed on one conidiophore. They are thick walled, light green in color, sub-cylindrical or obclavate, straight or curved, 3 to 10 septate and measure 40×140 microns by 11×21 microns. The spores germinate readily producing germ tubes from the end cells alone. The perithecia formed in culture media are black, spherical and superficial with long cylindrical beaks. They are 276 to 414 microns in diameter, while the beaks are 97 to 262 microns long and 55 to 83 microns wide. The asci are short, stipitate, straight, cylindrical, 1 to 8 spored, rounded at the apex, and measure 120 to 193 microns x 14 to 17 microns. The ascospores are ' yaline, cilliform, 11 septate and measure 120 to 193 microns ×14 to 17 microns. They are spirally coiled within the ascus and germination occurs from any or all of the cells. Pseudoparaphyses are often found with the asci (Ramakrishnan, L.C.).

Cochliobolus nodulosis grows well on agar media, but aerial growth is better in some substrates like rice meal than on others such as the French bean. Sporulation, however, is often inversely proportional to the amount of aerial growth. The spores germinate readily in water and the optimum reaction of the medium for growth is pH 7.1. The highest spore germination occurs at 100% relative humidity, but aerial growth is maximum when the relative humidity is maintained between 80 and 92%. Spores found on the grains have good viability even after a year's storage, but when stored at 10°C, the viability is lost after a week (Narasimhan, 1933; and Mitra and Mehta, L.C.).

Infection.—The blast fungus is seed-borne and primary infection is believed to result from the pathogen being carried on the seed. However, secondary infection in the latter stages of the crop is frequently initiated by air-borne conidia from secondary hosts or the fungus colonizing on stubbles and plant debris. Infection occurs between 10–37°C, but is optimum between 30–32°C. The spores germinate through the stomata, epidermal cells or epidermal out-growth of the leaves and the first sign of infection can be observed within 24 hrs. Conidia produced in lesions within four days of infection and susceptible small seedlings may be killed within three days while older seedlings may succumb after two weeks (McRae, 1932). Humid conditions favor the intensity of infection and certain ears appear to favor epidemic of blasts. In India, heavy blast was recorded in 1916 and in 1946 in Karnataka (Coleman, L.C.) and (Venkatarayan, 1946–47). A very severe attack occurred in complex form with other pathogens and possibly a virus in several portions of south western Karnataka and parts of Andhra Pradesh (Joshi *et al.*, 1966; Govindu and Shivanandappa, 1967).

Several hosts are cross-infected by the pathogen *C. nodulosus* including *Eleusine indica*, *Dactyloctaenium aegyptium*, *Setaria italica*, *Echinocloa frumentacea*, *Panicum miliaceum*, *Zea mays*, *Pennisetum typhoides*, *Sorghum bicolor* and *Saccharum officeanarum*. Wheat, barley and oats were reported not to be infected by this fungus by Mitra (1931) and Mitra and Mehta (L.C.). However, Thomas (1940, 1941) found that an isolate from ragi infected seedlings of wheat, barley and oats but not sorghum. The pathogen has also been shown to cause seedling blight leaf stripe and sooty heads in the common weed, *Eleusine indica*, in several countries.

Varietal Reaction.—As with blast, studies of varietal resistance to ragi blight are few and inconclusive. Coleman (1920) observed that green glumed strains were more susceptible than those having violet glumes. Venkatakrishnaiya (1935) found the most severely affected ragis of Karnataka included the Hullubele or Dodda types and the early Kar or Gidda strains in observations made in 1932. However, the improved strain H-22 appeared less susceptible than most of the others.

The susceptibility reaction to *Fusarium* sp. and *Cochliobolus nodulosus* for 13 cultivars of ragi collected in different states was investigated by Grewal and Pal (1965). They observed the least loss of seedlings through infection in the varieties Vellai surattai, Agni kuvaragu, and Kodah having 1, 2 and 3% loss, respectively. However, complete control was obtained by treatment with Agrosan G.N. In other studies carried out in Bihar by Misra and Bose (1966), ten strains of ragi were inoculated with single spore isolates of *C. nodulosus*. They obtained the highest manifestation of seedling blight and leaf spot infection and inhibition of shoot and root growth in the cultivar A 406 (AKP-3), and secondarily in the strains 61–588 and A 402 (NR 124); while least infection was observed in A 405 (AKP-7) and in the Pusa strain 54–1 (54–1–9).

Control.—Seed treatment with organomercury compounds has been reported to give good control of the primary infection. However, the secondary infection caused by air-borne conidia can only be controlled by protective foliage spraying with fungicides. The feasibility and economy of foliage spraying has not been worked out under different conditions in ragi growing regions.

SMUT (*Melanopsichium eleusis* (Kulk) Mundk and Thirum)

Ragi smut appears to have restricted occurrence in India where it is most prevalent in the States of Maharashtra and Karnataka. Kulkarni (1918) first collected this fungus in Kolhapur, Maharashtra where he described it as *Ustilago eleusinis*. A similar smut collected near Nairobi, Kenya, was described by Mundkur (1939). He also hypothesized that this pathogen differs from a species of *Ustilago* affecting *Eleusine indica* in China owing to their smaller ekinulate spores.

Symptoms.—Generally only a few seeds in an ear become affected, and the infected grains are scattered throughout the spikes. These are converted into enlarged globose sacs, greenish at first but later turning dirty black and 5 to 15 mm in diameter. Ear structures are hypertrophied and contain lysigenous cavities containing spores. At first the matrix is gelatinous but later the mass becomes pulverulent.

Pathogens.—The smut first named as *Ustilago eleusinis* was later transferred to the genus *Melanopsichium* by Mundkur and Thirumalachar (L.C.). The spores are globose in shape and 7 to 11 microns in diameter. The epispore is densely pitted and has a rough surface. The spores germinate readily in water, producing septate promycelia. Sporidia are formed on these both terminally and laterally. The fungus grows well on potato dextrose agar forming whitish colonies (Mundkur, L.C.).

Infection.—Early reports that the pathogen was seed-borne and thus controllable by seed treatment was disproved by Narasimhan (1922, 1934) and McRae (1924). Among the methods of infection tried by these workers and Venkatarayan (1947) included mixing the seeds with spores, inoculating the flowers with spores or sporidial suspensions, and injection of spores or sporidia into the seedling with a hypodermic syringe. These methods were unsuccessful, but Thirumalachar and Mundkur (1947) obtained successful infection when sporidial suspensions were poured on the ears at the time of head emergence. They therefore concluded that the infection was air-borne and occurred during flowering.

Control.—Control of smut is difficult because it is aerial spread and infection occurs during flowering time. Seed treatment does not help and varietal resistance has not been studied.

WILT OR FOOT ROT (*Sclerotium rolfsii* (Sacc.) Curzi)

This disease has also been named *Pellicularia rolfsii* (Sacc.) Curzi and *Corticium rolfsii* (Sacc.) Curzi. It was first reported in 1928 from Anakapali in Andhra Pradesh, but later found to be prevalent in Coimbatore, Tamil Nadu as well (Madras-DA, 1954). The pathogen, however, is very widely distributed and may infect ragi extensively in areas where the crop is grown. However, damage does not appear to be extensive but rather sporadic in nature.

Symptoms.—Infected plants are often pale green and stunted. The infection most commonly occurs at the base of the plants, on the leaf sheath and culm. These often turn brown at the place of infection; and the plants eventually wilt, lodge and dry up. Mycelial growth occurs prominently between the sheaths or on the stem at the basal region as a white fan-shaped growth. The sclerotia are formed on the surface of the mycelial growth as small mustard seed-like and tan-colored bodies (Ramakrishnan, L.C.).

Pathogen.—Only the mycelial and sclerotial stages of the pathogen occur in nature and are referred to as *Sclorotium rolfsii*, while the perfect stage is referred to as *Pellicularia rolfsii*. The fungus grows well on most of the commonly used agar media, producing the first sclerotia within about a week. Only certain isolates produce the perfect stage on specific media such as onion agar (Ramakrishnan, L.C.). The sporophores were described by Sprague (1950) as having a dense hymenium that does not form a continuous fleshy layer when fully formed. It is 30 to 40 microns in thickness. The basidia are obovoid and measure 7 to 9 microns × 4 to 5 microns. They bear 2 to 4 parallel or divergent sterigmata ranging up to 6 microns in length. The spores are elliptical to obovate, rounded on top, apiculate, hyaline, smooth, and measure 6 to 7 microns × 3.5 to 5 microns.

Infection.—The source of infection is from the soil, and the incidence of the disease is correlated with wet soil conditions. Control measures or varietal resistance have not been studied as the disease is only of sporadic occurrence.

Varietal Reaction.—The World Collection of *Eleusine coracana* was screened for resistance to a wilt/nematode disease complex occurring at Bangalore in 1965–66 by Govindu, *et al.* (1966). They observed differences in disease reaction among collections from the different Indian states. Of the 793 Indian varieties and strains included in this nursery, 322 were classified as resistant. The highest percentage of resistant lines had been collected in Tamil Nadu.

Downy Mildew (*Sclerophthora macrospora* (Sacc.) Thirum., Shaw and Naras)

This disease is also known as green-ear or crazy top and has synonyms *Sclerospora macrospora* Sacc. or *Phytophthora macrospora* Sacc. (Tanaka and Ito, 1940). It was reported by Venkatarayan (1947) as having occurred in Karnataka (Mysore) in 1930. Sporadic infection was observed in both early and late sown crops and the characteristic feature of the disease was proliferation of the earheads. A severe outbreak of the disease was recorded again in Karnataka in 1948. Light infection was later reported from Tamil Nadu and outside India the disease was recorded on ragi, *Eleusine indica*, and also on maize in the United States (Ullstrup, 1955).

Symptoms.—Infected plants are frequently dwarfed with short internodes and have pale green leaves, but these do not shred as in sorghum. The plants assume a short bushy appearance with numerous small leaves arising in close proximity. The disease is particularly obvious at heading time when normal spikes proliferate small leaf-like structures. The lemma, palea and sometimes the glumes are converted into these small leafy structures beginning with the basal spikelets and gradually developing in others to finally give the entire ear a brush-like appearance (Thirumalachar and Narasimhan, 1949).

Pathogen.—This fungus was first identified as *Sclerospora* sp. but this was later changed to *Phytophthora macrospora* by Tanaka and Ito (1940); but later Thirumalachar, *et al.* (1953) established a new genus *Sclerophthora* to accommodate this fungus which exhibits the oogonial and oospore characters of *Sclerospora* and the sporangial appearance of *Phytophthora* and it is now identified as *Sclerophthora macrospora.*

The fungus has been described by Ramakrishnan (L.C.) and also studied by Ullstrup (1955). A description of the different structures is as follows:

Hyphae.—intercellular in tissues, and is systemic.

Sporangia.—lemon-shaped with papilla at the apex and pedicel-like stalk remnants up to 100 microns in length.

Sporangiophores.—emerge through the stomata and bear a few sporangia measuring 75 microns × 47 microns.

Oogonia and oospores.—formed in the cells surrounding the vascular bundles in the affected spikelets, globose and thick-walled oogonium with oospores averaging 60 microns in diameter.

Infection.—There is very little information on the mode of infection of downy mildew in ragi. However, work done on *Sclerospora* affecting other cereals suggests that oospores in the soil or those adhering to the seed are the primary cause of infection. It is also likely that the fungus is spread by secondary hosts which are numerous and include, besides ragi, *Eleusine indica*, maize, *Eragrastis pectinacea*, and *E. cilianensis* and *Digitaria marginata*. Other hosts include wheat, oats and rice, but physiological specialization is well developed in this species and certain races may be specific to different hosts.

Control measures have not been worked out, nor are resistant varieties identified. Nevertheless, it is hypothesized that seed treatment would be helpful and Ramakrishnan (L.C.) recommends removing of sporadic affected plants to reduce the inoculum source.

Other Fungus Diseases

There are several other fungal diseases reported to occur on ragi in India and other countries where the crop is grown. These either have not been studied thoroughly or have not been shown to cause significant economic loss to the ragi crop. These pathogens are briefly described below:

Gibberella saubinetti (Mont.) Sacc. has been reported from East Africa, where it caused foot rot of ragi in Uganda. The infection occurs as patches in the field (Hansford, 1934; and Uganda-DA, 1933).

Phyllachora eleusinis Spet.—This has also been reported from East Africa, in Uganda and Tanzania and causes tar spot on ragi leaves (Small, 1922).

Helminthosporium sativum P.K. and B—This is reported from Coimbatore where it was found capable of infecting ragi leaves causing elongated spots (Ramakrishnan, L.C.).

Helminthosporium oryzae Breda de Hann—This pathogen has been identified with rice but has also been shown to infect ragi leaves (Nisikado and Miyake, 1922).

Helminthosporium rostratum—This leaf blight was considered serious on certain varieties and caused small intervenal straw-colored lesions (Lele and Dhanraj, 1966).

Curvularia lunata (Wakker) Boedijn—This has been reported to cause a minor leaf spot of ragi in India (Butler and Bisby, 1931).

Cercospora fusimaculans Atk.—This has been reported from Tanzania (Wallace and Wallace, 1947).

Cercosporella sp.—This pathogen was reported from Karnataka as causing leaf spot in ragi. The spores were reported to be similar to those of *Cercospora* (Narasimhan, 1921).

Collectotrichum graminicolum (Ces.) Wilson—This may infect ragi leaves as well as maize (Chowdhury, 1946).

Botryodiplodia theobromae Pat. has been identified on rotting culms of ragi in Ceylon (Sri Lanka) (c. Rev. Appl. Mycol. 6:1654, 1926).

Gloeocercospora sp.—This has caused severe blight of leaves in Malawi (Weihe, 1950).

Heterosporium sp.—This is a disease of ragi grain stored under unfavorable moist conditions. Consumption of such grains may cause vomiting and intestinal disorder (Narasimhan, 1929; and Venkata-Rao, 1930).

Ozoniumtexanum var. *parasiticum*—This pathogen has been identified as causing wilt of *Eleusine coracana* in Bihar, India (Chakravarti and Ghufran, 1964).

Tatter spot (*Phyllachora eleusines*)—This causes small, jet black, brown and slightly raised spots or lesions which are irregularly distributed on both sides of the leaves. The disease is usually most prominent and obvious as a crop approaches maturity (Dunbar, 1969).

Cylindrosporium leaf spot (*Cylindrosporium* sp.) —Oval black spots on leaves with white powdery centers are the distinguishing symptoms of this pathogen. It is not a serious disease of the crop in Uganda (Dunbar, 1969).

Bacterial Diseases

The earlier literature on ragi diseases includes very few references to bacterial diseases. One of the first reports came from Uttar Pradesh in India (Mehta and Chakravarty, 1937). They described the affected plants to be stunted in growth and possessing a tufted bushy appearance as a result of numerous lateral shoots arising from the upper nodes. Ears were not formed or proved sterile, but numerous adventitious roots developed from the upper nodes. At first the foliage is pale green, but later turns to brown. The brownish patches on the stem are slimy to touch and microscopic examination reveals the phloem to be discolored and bacteria present in the intercellular spaces.

Investigations on bacterial diseases were reported by Rangaswami *et al.* (1961) working at Annamalai University, Tamil Nadu. They found a bacterium causing a minute leaf spot and stripes on *Eleusine coracana* and named it *Xanthomonas eleusineae.* They found the pathogen would also infect maize. In subsequent investigations on this pathogen, Desai *et al.* (1965) found *Xanthomonas eleusineae* was neither pathogenic nor a *Xanthomonas* sp. However, the authors discovered a new species, isolated from *Eleusine coracana* in several localities proved its pathogenicity and designated it *Xanthomonas coracanae.* Investigations on control of bacterial blight were conducted by Desai *et al.* (1968). They advocated growing fairly resistant varieties and applying Streptocyclin during the infective period.

Virus Diseases

A mosaic virus disease which causes mottling of the leaves has been recorded by several observers in different parts of India; at

Visakhapatnam in Andhra Pradesh (McRae, 1929), at Coimbatore, Tamil Nadu (Madras-DA, 1954), in Karnataka (Venkatarayan, 1946) and in the Deccan region of India (Rao, *et al.*, 1965). The common symptoms observed include pale green and mottled leaves, failure to produce ears and elongated chlorotic streaks interspersed with light green patches. However, seeds formed from the diseased plant gave rise to healthy progeny. Affected fields were frequently infested by possible insect vectors like *Aphis maidis*. Sometimes nearby fields of other crops including sorghum showed symptoms of a mosaic type.

Early work on sap inoculation and tissue transplantation did not produce successful transmission of the disease. However, Cherian and Kylasam (1936) described a virus disease on sorghum called 'freckled yellow' that could be transmitted to ragi. Symptoms included minute creamy-yellow specks or dots arranged in a line between the veins or the leaves. These spots became more pronounced in later developing leaves. The shoot bug *Peregrinus maidis* was found to be the vector. In later studies, this disease was named *Eleusine* mosaic virus by Rao *et al.* (1965) who observed it on *E. aegyptica*, *E. indica* and *E. coracana*. This virus was transmitted by several sucking insects to a wide host range including sorghum, maize, *Setaria italica*, and *Elettaria cardamomum*. It was inactivated by heating to 55° to 60°C, dilution to 1 part in 15, and ageing more than 2½ hrs at room temperature.

Some other viruses have been reported as affecting ragi, including one reported by Smith (1957) who observed sporadic symptoms on ragi resembling those of maize streak virus. Another virus shown to infect *Eleusine indica* is the leaf-gall virus of rice in the Philippines (Agati and Calica, 1950).

Phanerogamic Parasites (*Striga* spp.)

Two flowering plants are parasitic on several graminaceous hosts in Asia and Africa. *Striga asiatica* Kentze and *S. densiflora* Benth have been known to attack sorghum and several other millets besides ragi in Maharashtra, Karnataka, and Tamil Nadu. Venkatarayan (1947) reported the occurrence of *Striga asiatica* in Karnataka and Srinivasan (1947) observed the parasitism of *S. densiflora* on ragi at Coimbatore, Tamil Nadu. Both the rainfed and irrigated crops are susceptible to infection. The parasite produces very tiny seeds which persist in the soil for very long periods. They appear to be stimulated to germinate by the presence of root growth of specific host species like certain millets, sorghums or maize. Upon germination the seed generates haustoria which penetrate the root of the host obtaining its required assimilates from this source. As the parasite develops, its above ground portions produce leaves and eventually it becomes semi-independent of the host. Therefore, in the initial stages of host development, the parasite is much more damaging to plant growth and productivity, while in the stages of the parasite development it becomes more or less independent of its host.

Control.—There is virtually no information on control of *Striga* in ragi. In fact, the control for this pest in other graminaceous hosts has not been well worked out. General recommendations are to weed out the parasite in the early stages of growth before flowering to prevent dissemination of the seed. Early sowing of the ragi crop was also recommended to permit the crop to mature before the parasite ripened its seeds. Harvesting would be followed by early ploughing to destroy the ripening parasitic plants before seeds could be produced. Another method recommended under certain conditions is the sowing of a susceptible trap crop to be ploughed under soon after the parasite had germinated its seeds. The main season crop would follow immediately thereafter and should be relatively free of the infection. Some work on selective weedicides is also mentioned. Striga is susceptible to 2,4-D and similar chemicals and these have been shown to be successful in small scale experiments.

The plant parasite *Striga hermonthica* is an important pest of ragi in East Africa. Control measures involve uprooting before seeding, crop rotation and the possible use of chemical herbicides. It should also be possible to find resistant varieties as these occur in other crops like sorghums and some of the other millets.

Non-Pathogenic Disorders

Plant growth may sometimes be inhibited or the crop may show abnormalities or symptoms of disorders which are not identifiable as being caused by any transmittable pathogen nor to deficiency of any of the major nutrients required for normal growth and productivity. These are often attributable to genetic factors, specific conditions of the environment, or an interaction of the genotype and environment.

Genetic.—Many pathogenic diseases cause sterility or failure of the ragi plant to set seeds. However, such sterility can also be caused by readily identifiable genetic factors. In cases of genetic sterility, the plant grows normally and produces what appears to be normal inflorescences, but the anthers may fail to dehisce or the pollen grains may be empty or in agglutinated masses. The inheritance of such sterility was described by Ayyangar (1932). Normal dehiscence of the anthers and the looseness of pollen grains are governed by two separate dominant factors which, in the recessive condition, results in sterility. Other types of sterility controlled by multiple factors have also been observed.

Soil conditions.—The effect of abnormal soil conditions causing disorders of the ragi plant have also been reported. Coleman (1920) observed stunting in growth and abnormal growth during seasons and localities where the soil is excessively wet during the early period of growth. For example, in the violet glume types, the leaves and stems acquire a reddish tinge later changing to a deep reddish color, whereas in the green glume types the discoloration is to pale yellow. Soil alkalinity may also have an adverse effect on the ragi plant as reported by Mehta and Chakravarty (1937). They studied a plot of ragi at Benares, India, which had effective drainage and where the soil was known to be slightly alkaline in reaction. The plants observed were stunted in growth and had a pale tufted appearance as a result of the suppression of apical growth and formation of numerous lateral shoots on the upper nodes. They also noted profuse development of white, unbranched adventitious roots around the nodes even from the upper ones. The affected plants usually did not produce fertile shoots and had short internodes but tillering was normal and the plant survived the full length of season.

Nutritional Disorders

Investigations on deficiencies of specific nutrients including major and minor nutrients have already been discussed under the appropriate sub-section in Management Investigations. Deficiencies of nitrogen and phosphorus are well known in those regions where ragi is grown. These include the classical light green color, poor and stunted growth, reduction in tillering and earhead size, purpling of leaves and leaf sheaths, and poor grain filling.

INSECTS AND ANIMAL PESTS

The Eleusines are reputed to be relatively free of insect pests. This is not really accurate in the light of most observations. The crop can be a host to a wide range of chewing and sucking insects which attack it in all stages of growth from the seedling through the mature plant and seed formation stages. Perhaps it would be more accurate to say that the need to control pests like the stem borers are less frequent on ragi than on some other crops such as sorghum. Moreover, such heavily damaging pests as the shoot fly and midge which attack the young seedling and the developing grain, respectively, have not yet been recorded as affecting the Eleusines. This is not to imply that insects do not cause havoc to ragi nor that they can seriously limit the cultivation of the crop in certain areas. However, such attacks appear to be somewhat more sporadic in occurrence and less devastating than on other cereals. Thus control measures may be somewhat easier and more obvious than for stem boring pests which are all but immune to chemicals once they are inside the stem.

There is not a considerable amount of literature on ragi pests. However, some preliminary investigations have been carried out in the two major growing regions of south-central India and East Africa. In the following discussion of important insect pests of ragi in the major growing regions of this crop, no attempt will be made to describe the pests in detail or follow their life history or habits, since these are more properly covered in some excellent entomological references on the subject. Neither will control measures, particularly those involving chemicals, be described in great detail inasmuch as the technology of insect control is changing very rapidly and the restrictions on chemicals having broad biological implications are often complex and differ from country to country and state to state. Rather, the object is to identify the pest reported to attack ragi in different areas and briefly describe the damage it caused to the crop.

India

Most of the insect pests attacking ragi in India are polyphagous, i.e., they may have several hosts among the economic plants and weeds of the region. They are root feeders, stem borers, foliage chewing and sucking pests, those which attack the developing head and seeds and finally stored grain pests.

Locusts and Grasshoppers.—Only three species of grasshoppers have been recorded as causing significant and consistent damage to ragi on the Indian sub-continent. Kevan (1954) describes species of *Chrotagonus* important in the Indian sub-continent. *Chrotagonus trachypterus* (Blanch.) is important in Pakistan and north-western India; while *Chrotagonus oxypterus* (Blanch.) occurs in south India. Coleman (1920) also mentioned a *Chrotagonus* sp. having the common name, surface grasshopper, as occasionally damaging to ragi in Karnataka. However, he and most other observers consider the Jola or the Deccan grasshopper, *Colemania sphenoroides* (Boliv.) to be much more important in Karnataka (Mysore Entomology Section, 1945–46), in Tamil Nadu (Madras-DA, 1954) and in Maharasthra, but not along the coast of that state nor in Gujarat (Kadam and Patel, 1955).

Serious outbreaks of the Deccan wingless grasshopper have been observed to occur periodically in Karnataka and other regions of India. Iyer (1932) reported that this pest re-occurred in 1924, after an absence of about 14 years, and caused very severe damage to both ragi and sorghum. The epidemic occurrence of this pest lasted until 1928. Subrahmanyam (1941) described the occurrence of *Colemania sphenoroides* at intervals of 10–15 years and reported that most serious damage occurs to the millets including sorghums, Eleusines, Pennisetums and Setarias when sown during the south-west monsoon rains. He states that damage is greatest during the third and fourth years of an outbreak, that it is slight in the fifth year and ceases until the next outbreak.

Measures adopted for the control of the Deccan grasshopper have changed drastically over the past 25 years with the development and use of the chlorinated hydrocarbons and organo-phosphates. In earlier times, departments of agriculture might recommend the construction and use of a hopper dozer, consisting of a wide bag or container opened towards the front and which is pulled briskly through standing crops to catch hoppers which would fly into them while moving. Another recommended control was baiting the affected areas and around the boundaries of fields to be protected with molasses-sweetened bran and treated with fast green or calcium arsenate. More recently the application of 10% DDT dust at the rate of 10 to 25 lb/acre is a recommendation for hopper control.

Foliage Caterpillars.—Several foliage eating caterpillars are reported to attack ragi more or less regularly in south and central India. In Karnataka this includes:

1. *Amsacta albistriga.*—The red-headed hairy caterpillar (kamblikula). This pest appears periodically from May to September in certain areas. It has a red head and stiff, bristly black hair covering the body. It causes extensive damage to young crops in parts of south-western Karnataka.
2. *Diacrisia obligua.*—The black-headed hairy caterpillar (kamblikula). This pest seems to become sporadically important every four or five years. The caterpillar when fully grown is large, about 6 cm in length, stout, cylindrical, and colored dark brown with black hairs and a distinct dark colored head.
3. *Cirphis unipuncta.*—The armyworm occurs sporadically every four or five years during September to December. The caterpillar is 3 or 4 cm in length, has a smooth cylindrical body with brownish wavy lines on the sides. As the name suggests it is gregarious often moving in large numbers.
4. *Laphyma exigua.*—The cutworm. The caterpillar is smooth, has a cylindrical, brownish green to dark brown body with white lines along the sides; it measures 2.5 to 3 cm in length and curls when touched.
5. *Plusia* sp.—The looper caterpillar of ragi. This pest attacks irrigated ragi more than the dryland crop. The caterpillar is 3 to 4 cm long, has a greenish-grey body with small wart-like tubercles. It feeds on leaf blades. It also cuts leaves, fastens them together and lives under the shelter.

The controls are more or less similar for these caterpillars; 5 to 10% DDT or BHC dust or spray, or poison bait (Coleman, 1920; Myscre E.S., 1945-46).

The same foliage caterpillars are reported to occur in the adjacent states of Tamil Nadu, Andhra Pradesh, and Maharashtra. In Karnataka the black hairy caterpillar is considered most important while in Maharashtra and Gujarat, the red-headed hairy caterpillar, armyworms and cutworms are listed as the most important pests of the monsoon ragi crop in certain regions (Madras-DA, 1954; Kadam and Patel, 1955).

Occasionally, one hears of a new insect pest attacking a crop; or a well-known insect not previously observed to attack a specific crop suddenly does so and perhaps seriously. For example, Puttarudraiah and Raju (1952) reported that *Azazia rubricans* (Boisd.) which is considered a pest of pulse crops in India is observed to severely infest ragi in certain villages of Karnataka. The larvae defoliated the plants which remain bare except for the ears. This pest also attacks sorghum, Setaria millet as well as cowpeas and *Dolichos lablab*. When mature the larvae pupated within silken cocoons in folded leaves or immediately below the soil surface. Another new pest of ragi in Karnataka was reported by Usman (1967). He identified *Lema downesi* as attacking ragi during June to September 1966 in Magadi, Bangalore, India. He suggested that this usually harmless insect might possibly become a pest of young ragi under certain conditions.

Earhead Caterpillars.—Several species of Lepidopterus larvae cause damage to the developing seeds in ragi earheads. Total damage varies considerably with the variety, the season and other factors. The more compact or tight-fisted varieties are generally more susceptible to attacks and they provide hiding places for the caterpillar within the closed head. In northern India at Pusa, Bihar, Fletcher (1921) listed three caterpillars as causing damage to ragi earheads in that region. These included *Heliothis armigera* Hb. (noctuidae), *Parthesia zanthorrhea* Koll. (Lymantriidae) and *Stenachroia elongella* Hmpsn. (Pyrolidae). In Karnataka, Puttarudriah and Channabasavanna (1950) identified *Cacoecia epicyrta* Meyr. as causing damage to developing ragi ears in that state. In Tamil Nadu, *Sitrotroga cerealella* Oliv. (Golechiidae) was observed by Subramaniam, *et al.* (1959) to be fairly widespread in the Coimbatore area. In subsequent studies at Coimbatore, David, *et al.* (1962) recorded five different caterpillar species as attacking ragi earheads at Coimbatore:

1. *Cryptoblabes* sp. (Pyralidae).—This webbing caterpillar feeds on the grains from inside the ear. It pupates inside a silken web attached with debris and faecal matter of the caterpillar.
2. *Eublemma silicula* Swinh. (Noctuidae).—This pale yellowish caterpillar also produces a silky web and feeds within the ear on both milky and mature stages of grain. The adult moth has reddish buff colored wings with wavy lines.
3. *Heliothis armigera.*— This pest feeds on developing grains hidden

within compact ears, but when full grown it drops to the ground and pupates in the soil.

4. *Stathmopoda theoris* Meyr. (Heliodinidae).—This caterpillar was not observed in large numbers and tended to feed on the more mature grains in the head. The larvae are light black in color with a black head and prothoracic shield, while the moth is small with narrow yellowish wings, the apical portions of which are brown.

5. *Sitrotroga cerealella* Oliv.—This grain moth was observed infesting standing crops in the field.

The first three insects described above were found to occur in all seasons and to generally cause severe damage. The other two were observed only occasionally and in small numbers. Totally, the infestation was observed to range between 26–38% but only the first three species mentioned occurred during the early stage and milky stage of the crop.

Stem Boring Insects

There are at least three stem boring caterpillar pests of ragi in central and southern India that sometimes assume serious proportions (Madras-DA, 1954; Kadam and Patel, 1955). These are the following:

1. *Sesamia inferens* W. (Noctuidae).—This pest bores into the stem and kills the central shoot. The plant is stimulated to tillering. The new shoot can be attacked in turn. The caterpillar has a uniform light pinkish color and also occurs in wheat, maize, sugarcane and sorghum, on which it frequently causes even more severe damage.
2. *Saluria inficita* W. (Pyralidae).—This is known as a white stem borer being creamy white in color. It also occurs on rice in Karnataka and normally bores in the lower portions of the stem.
3. *Chilo zonellus* Swinh. (Pyralidae).—This pest is known as the sorghum stem borer. It is a far more serious pest on sorghum. It bores into and tunnels in the stems of the crop causing death of the stem in the earlier stages and greatly reducing grain set and filling in the later stages of growth.

The borer of greatest economic importance is probably *Sesamia inferens* which is primarily a pest of sugarcane and other cereals. Krishnamurthi and Usman (1952) made detailed studies of the life cycle and economic loss caused to the ragi crop in Karnataka.

Although *Sesamia* is primarily a pest of sugarcane, sorghum and other cereals, it often causes some loss in ragi crops as well. They found infestation ranging from 1 to 3% in moderately infested fields to 5 to 6% in the most severely infested crops. It was observed to be particularly damaging when the ragi plant is in a suitable stage of development, i.e. before the stem becomes mature and hard. They found the insect to have four generations a year under Karnataka conditions and that the duration of the life cycle averaged 45.6 days in summer and 71.1 days in winter. Three insects were observed to parasitize the larvae, three other predators attacked the pupae and one, *Trichogramma minutum* Ril, parasitized the eggs in the laboratory but not in the field.

Besides the Lepidopterus stem borers, a shoot fly, *Atherigona miliaceae* Mall. (Anthomyidae), was reported by Sengupta (1957) to attack seedlings of *Eleusine coracana*. Other species of Atherigona are extremely serious pests of sorghum, other millets and maize in India and in Africa.

Control of stem-boring pests is extremely difficult once the larvae have tunnelled into the stem. However, the young larvae are extremely vulnerable to insecticides during the stage between hatching from the eggs which is frequently laid on or under the leaf blades and the stage when they commence tunnelling into the stem. Often the young larvae remain on the foliage feeding on the tender young leaves at the top of the plant before tunnelling into the stem through the leaf whorls. Several chlorinated hydrocarbons, organo-phosphates, or carbamates have been shown to be highly effective in reducing borer infestation when properly applied during this early stage of larvael development. Granular formulations are particularly effective and convenient to use when placed in the leaf whorls in the developing plants. With such placement, the insecticide is at the focal point of attack and largely has little or no effect on beneficial insects or predators. Other controls involving cultural practices should result in greatly reducing infestation. The cleaning up and destroying of crop residues as well as alternate hosts for these pests coupled with simultaneous planting of the crop should greatly reduce incidence and economic loss from stem borers. From the standpoint of biological control, as previously noted, there are several insect predators which parasitize different stages of the insects' non-sexual life cycle.

Unfortunately, these parasites usually build up more slowly than their hosts and thus do not prevent much of the damage that occurs to the crop at least in the early generations of the season. Parasitism of up to 20% has been observed in *Sesamia inferens* (Krishnamurthi and Usman, L.C.).

Sucking Insects

Three types of sucking insects have been reported to cause damage to ragi plants in India. Thrips (*Heliothrips indicus* H.) sometimes cause trouble in ragi nurseries by sucking the plant juices in the young seedling stage. In central India, aphids (*Aphis maidis* F.) sometimes occur on ragi but are more common on sorghum, maize and other cereals. However, another species of aphid (*Microsiphum leelamaniae* sp. N.) was observed by Kanakaraj (1958) to attack ragi at Coimbatore. Perhaps even more serious is a root aphid (*Tetraneura hirsuta* B.)-, causing very severe damage to ragi in parts of south India and in the region of Coimbatore, Tamil Nadu. This aphid attacks the roots with the result that infested plants are dwarfed in size and slowly wither away. Frequently, large numbers of ants occur in association with this aphid.

Sucking insects have traditionally been difficult to control, but the advent of several very good systemic insecticides, particularly amongst the organo-phosphates, offer excellent possibilities for control if the economics are worked out and proved feasible. The possibility of biological control may also be promising. For example, the Coccinelid ladybug is a well known and valuable ally in the control of aphids (Madras-DA, L.C.; Kadam and Patel, L.C.).

Bugs and Beetles

There are two major species of beetles reported on ragi crops in south India (Madras-DA, L.C.). The flea beetle *Chaetocnema* sp. attacks the tender young foliage by eating away the leaf blades. These beetles are very small and occasionally cause economic damage to the extent that control measures are indicated. Another beetle (*Lema downsei* B.) earlier reported from Tamil Nadu by Usman (1967) was observed for the first time to attack the young ragi crop near

Bangalore, Karnataka. He believed that the pest might possibly assume economic proportions under favorable conditions. A much earlier report on a third species—the Ground beetle (*Gonocephalum hoffmannseggi*)—was recorded by Coleman (1920) to attack young ragi plants in certain parts of Karnataka.

Definitive studies on control of beetles on ragi have not been reported. Perhaps most investigators have felt these pests did not cause sufficient damage to warrant the expense of adopting control measures. Nevertheless, they should be relatively simple to control with dust or sprays of several modern chemical insecticides.

White Grubs

There are two major species of white grubs that occur as pests of crops in India. These include *Arthrodes* sp. and *Holotrichia* sp. (Melolonthidae). The white grub often has a rather wide host range causing serious damage to several of the graminacious crops and groundnuts under certain conditions in India. Reports on specific damage to ragi are very few, but Rangarajan (1966) working at Coimbatore investigated several chemical controls for white grubs in ragi. He found that BHC, DDT, chlordane, lindane, dieldrin, parathion, heptachlor and aldrin applied to the soil at 2 lb of active ingredient per acre controlled *Holotrichia* sp. on *Eleusine coracana* for up to two months.

Midges

Several species of gall midges attack sorghums and Panicum millets in the major growing region of Asia and Africa. The most common of these associated with sorghum and Pennisetum millets are *Contarinia* sp. and *Cecidomyia* sp. These have been intensively studied by Harris (1954) and Harris (1956). In India an unidentified gall midge resembling the rice gall midge (*Pachydiplosis oryzae* Mani) has been recorded to also occur on Eleusine. The occurrence of gall midges in Eleusine inflorescences have not yet been recorded from India, but an erroneously-identified gall midge very similar to *Contarinia sorghicola* was reported as living in the inflorescence of Eleusine in Uganda. Since very little is known about the importance and extent of damage of gall midges in ragi, control measures are neither proposed nor suggested.

Bug Pests of Developing Seeds

The rice bug, *Leptocorisa varicornis* F., is a widely distributed major pest of rice in India. It causes injury to the developing grains by sucking the juices from the developing seeds principally in varieties maturing before the end of October in northern India. Among its alternate hosts are *Eleusine coracana* and three other millet species. It appears to build up on alternate hosts during the years when showers in April and May are accompanied by temperatures ranging between 85–100°F and then spreads to rice fields with the advent of the monsoon, sometime in July. Control of the pest was attained by dusting with 5% BHC at the rate of 20–25 lb per acre and applied in the afternoon on calm days (Sen, 1955).

Stored Grain Pests

One of the major reasons for growing ragi is its excellent storability under tropical conditions. It is reputed to remain in good condition when stored for very long periods even up to several decades under moderately satisfactory conditions such as straw-lined underground pits in well-drained areas. However, some pests will attack the grain particularly before it has properly dried or when conditions are less than ideal. In Tamil Nadu, an earhead caterpillar (*Simplicia roubstalis* G.—a Noctuid) frequently attacks the ragi earhead in stacks immediately after harvest. The recommended control was to thresh the crop as soon as possible after harvesting. In Karnataka, the most common stored grain pests of ragi are *Thizopertha dominica* F. and *Alphitobius* sp. (Krishnamurthi 1945). Control measures recommended include storing in a dry, airy warehouse and not in direct contact with floor or walls. Previously infested grains should be fumigated and thoroughly aired afterwards. For long term storage, keeping the grain in tight bins with a layer of sand on the cover and removing the grain as needed from the bottom by means of sliding doors was recommended.

The natural resistance of different grains to insect attack have been studied by several investigators. Pruthi and Singh (1944) found several of the millets including *Eleusine coracana* and other Panicum sp. to remain free of attack even for up to two years under conditions where the insect had free access to the grain. In other storage studies with the rice moth, *Corcysa ephalonica*, Ramaswami, *et al.* (1942) said that sorghum with high nitrogen and fat content had more insect damage compared to ragi having relatively lower contents of these two constituents. They attributed the poor insect growth and development on ragi as resulting from the low fat content of the grain.

Africa

Investigations of pests of finger millet in Africa are largely confined to those regions where the crop is relatively important. These are from Ethiopia southward to Zambia and southern Rhodesia, in the east, including Uganda, Kenya, Tanzania and Malawi; and in central Africa particularly Rwanda, Burundi, Zaire (the Congo) Cameroons and even a small extension into Eastern Nigeria. However, most sources of information were from Uganda where ragi is the most important grain crop of that country.

Locusts and Grasshoppers

Grasshoppers were considered the principal insect pest of ragi and other species of Eleusine in Uganda by Hargreaves (1939). He reported the pests to be mainly injurious in the drier areas and that they cause the most severe damage when millet is sown before the rains as the young plants are eaten when they first emerge after early showers when they are the only green leafy food available. In a later report Hargreaves (1940) described swarms of locusts (*Nomadacris septemfasciata* Serv.) concentrating in the foothills of the Ruwenzori at altitudes of 4,500–8,500 ft. during April and May, 1939 and causing extensive damage not only to finger millet but to other crops like maize, banana, beans, cotton, sweet potatoes and cassava. He further observed that later in the season large numbers of the adult were killed by the fungus *Empusa grylli.* The same author described an earlier outbreak in the spring of 1939 of hoppers (*Locusta migratoria migratorioides* R. and F.) that occurred in the West Nile province of northwestern Uganda. These swarms had migrated south into Uganda causing serious damage to finger millet, maize, sorghum, rice, and bananas. He also observed eggs of the locusts were parasitized by *Stomatorrhina lunata* F. and that several adults in the swarms contained an unidentified tracheal mite.

Several other acridis have been reported to attack finger millet in Uganda. Darling (1946) identified the following species infesting Eleusine in northwestern and Ankole district: *Humbe tenuicornis* Schaum., *Oedaleus* sp., *Acrotylus* sp., *Paracomacris* sp., *Sumba* sp., *Roduniella* sp. and *Catantops melanostictus* Schaum. Kevan (1954) reported that *Chrotagonus senegaliensus abyssinicus* Bol. caused seasonal damage to finger millet in Uganda. Dunbar (1969) described two species of grasshoppers causing substantial damage to finger millet in Uganda. The first of these was a *Chrotogonus* sp. and the second, the elegant grasshopper (*Zonocerus elegans*). The latter is large, up to 5 cm in length, has a yellowish head and thorax, green wings with orange, yellow and black banded ribs and is very gregarious. It has a wide range of hosts including the cereals, cassava, coffee, castor, cacao and cotton. As a control Dunbar recommended 142 cc of dieldrin 18% missible liquid in 9 litres of water applied directly on the grasshoppers.

Stem Borers

The principal stem borers of finger millet in East Africa are probably the pink stalk borer (*Sesamia calamistis* Hmps.) and the sorghum borer (*Chilo zonellus* Swinh.) (Dunbar, L.C.; Nye, 1960). The pink caterpillars range up to 1 in. in length, bore into stem causing dead hearts and occur in scattered patches of plants. Two other species of stem borers described as affecting both bulrush and finger millets in Kenya are the maize stalk borer (*Busseola fusca*) and the coastal stalk borer (*Chilo orichalcociliellus*). Other symptoms caused by both borers involve holes in the young leaves and later dead hearts as the caterpillars tunnel into the stems. The maize stem borer tends to work in tillers, ranges up to 4 cm in length, and is whitish or pinkish with small black spots along the body. The coastal stalk borer causes similar symptoms but also causes yellow streaks where the very young caterpillars have been working on the leaves. The larvae are creamy pink with groups of dark spots along their bodies and range up to 2.5 cm in length. Ingram (1958) suggested that *Chilo zonellus* Swinh. may have been a recent introduction into East Africa. He also observed that it was not found above 4,000 to 5,000 ft. elevation and that it caused the most severe damage in dry years and on out-of-season crops.

Specific control measures involving the use of insecticides are not recommended for stem boring pests in millets in East Africa as the plants largely compensate for the damage by producing extra tillers. Nevertheless, it is strongly recommended by departments of agriculture for millet growers to destroy their previous seasons' residues to eliminate insofar as possible the alternate hosts of stem borers; and to plant early all of their crops at the same time in order to reduce the incidence of these pests. Fortunately, finger millet is usually less susceptible to attack than sorghum and other millets. Ingram (1958) found the least incidence of stem borers being 10% in finger millet compared with 89% in sorghums and 34–50% in some other grasses. He also observed the life cycles to range from 68 to 75 days for *Busseola fusca*, 46 to 58 days for *Sesamia calamistis* and 46 to 53 days for *Chilo zonellus*.

Foliage Caterpillars

Army worms, *Spodoptera* (*Laphyma*) *exempta*, caused periodic outbreaks at intervals of several years in Uganda, according to Hargreaves (1939) and Dunbar (L C.). The caterpillar, ranging up to 2.5 cm in length with a velvety black stripe down the center of the back, bordered by paler gray green stripes and with a thick black line along the sides and green underneath, occurs periodically in very large numbers to devastate grazing lands and finger millet plots. The pest is controlled by a 25% missible DDT liquid, 425 cc added to 9 liters of water and applied over 1/10 hectare or used as a barrier spray.

Bugs and Beetles

The Lygus bug (*Lygus simonyi* Reut.) attacks young finger millet in Uganda. It feeds principally on rapidly growing tissues such as buds, young stems, or leaves. It is perhaps more important on cotton since it migrates from millet or sorghum following the harvest of those crops to cotton fields in the grass zone of northeastern Uganda, (Taylor, 1945; Geering, 1953). Taylor also observed that Lygus nymphs were parasitized by two unidentified species of *Euphorus*, thereby helping in the control of this pest. Although the extent of damage to finger millet caused by Lygus is largely under-toned, another implication is its migration from sorghum and millet fields following harvest to cotton fields in north and eastern Uganda in the short grass zones.

The phytophagus ladybird beetle *Epilachna similis* Thnb. has caused serious injury to grain crops in Kigezi and Ankole. It has defoliated Eleusine and rice and to a lesser extent maize.

Two other black beetles, *Cyaneolytta regipennis* and *Eipcanta limbatipennis* are mentioned by Dunbar (L.C) as causing severe damage to seedling millet at the beginning of the rain. These two beetles are blue-black or black ranging from 2.5 to 4 cm in length and are most likely to cause damage at the beginning of the rainy seasons. They can be controlled by spraying directly onto the insects 425 cc of DDT 25% M.L. in 9 liters of water.

In Kenya, the shiny cereal weevils (*Nematocerus* spp.) cause damage to millets by eating stems and leaves and cutting young stems at some distance above the ground. These are black weevils with bronze reflections and are 6 to 12 mm in length. The larvae are white, legless, wrinkled, C-shaped, and up to 12 mm long. The larvae feed on roots, young stems below the soil surface and on seeds. There is no known control (Wheatley and Crowe, 1967).

Midges

Midges attacking sorghums and other graminaceous plants were studied by Geering (1953). In his studies of the Cecidomyiid attacking sorghums (*Contarinia sorghicola* Coq.), he found a midge which could be reared from *Sorghum verticilliflorum*, a grassy weed, and *Eleusine coracana*. The insect was morphologically indistinguishable from *Contarinia sorghicola*. However, Barnes (1954) claimed the midge on Eleusine was definitely not *C. sorghicola* but that it is a distinct species which has not yet been identified.

Conclusions on Diseases and Pests

The available evidence suggests that finger millet may be relatively less subject to many diseases and pests compared with several other graminaceous crops. On the other hand, it is quite obvious that there is a great dearth of information regarding the extent of damage, the conditions under which attacks occur, and various means of alleviating them insofar as *Eleusine coracana* is concerned. Among diseases, blast caused by *Pyricularia* sp. and blights caused by *Cochliobolus nodulosum* (*Helminthosporium nodulosum*) are the two most important diseases of this crop in its major growing regions. It is very encouraging that fungicidal seed-dressings are at least partially effective against blast. It also appears quite obvious that important breeding objectives would be to make intensive searches for varietal resistance to these pathogens within the World Collection of Eleusines. Other very useful investigations would involve study of the exact environmental conditions predisposing the development and build-up of these diseases. Moreover, an assessment of their contribution to reduced yields under various levels of infection would be most helpful in establishing priorities regarding the improvement of this potentially useful crop.

Regarding insects, ragi is in the fortuitous position of not having many seriously limiting pests. Moreover, those that appear capable of causing the most extensive damage to this crop, which include locusts, foliage and earhead caterpillars, beetles and certain sucking insects, are relatively easy to control by comparison with pests like stem borers, midges and stored grain pests. Regarding the latter insects, ragi has a tremendous advantage for humid areas lacking adequate storage facilities in being nearly immune to most storage insect pests. This is undoubtedly a major asset in many of the growing areas like tropical Africa and Asia. Among animal pests, birds are a major problem in many areas but generally much less so than for other graminaceous crops, namely sorghum, rice and bulrush millet. There are no reports of damage from rodents like rats and squirrels where these pests occur.

THE PRODUCT

The seeds of finger millet are relatively small and hard. Normally, 300–450 seeds weigh only one gram (150,000–200,000 seeds per pound). The grain of brown-seeded strains is somewhat low in protein ranging from about 6.0–7.5%. However, some strains, particularly white-pearly seeded types, may run much higher in protein.

Ragi grain is good for both humans and animals. It is particularly high in calcium averaging about 0.34% of the whole grain or about eight times that of whole wheat. Perhaps even more important is its relatively high methionine content, ranging from 2.0–3.7% of protein. This is particularly important in some tropical regions like that around Lake Victoria in East-Central Africa where the sulphur-bearing amino acids are the most important protein deficiency.

Ragi grain is relatively high in fiber content averaging about 3.6%. This is not always considered undesirable as it appears to slow the rate of digestion. Thus, peasants accustomed to eating ragi can "work all day" on a single meal of ragi. In fact the grain is often preferred for its taste in ragi growing regions like southern India and East Africa. Jowett (1966) found a mixture of cassava, sorghum and ragi was preferred over maize and pearl millet.

Another valuable asset of ragi is its malting quality. It is frequently an important constituent in local beer making. Sometimes it is the major constituent, but frequently it is added to sorghum and other carbohydrate sources like malting bananas (mwenge type). The ragi enzyme was found to have a saccharifying power greater than the corresponding enzymes from sorghum or maize malt but less than that of barley malt amylase (Patwardhan and Narayana, 1930).

The stover remaining after grain harvest is often considered valuable cattle feed. It may be preserved in stacks or cattle are allowed to graze the stubbles if the seed heads have been removed from the standing plants. The digestibility of ragi straw was found superior to that of paspalum millet, wheat and sorghum in having 60.8% total digestible nutrients in studies carried out by Patel, *et al.* (1961). In certain regions of Ethiopia, the tough, wiry culms of a semi-cultivated species (*Eleusine jessamine*) are used for making baskets and native grain sieves.

Storage

A major advantage of ragi grain is its excellent storability. The small flinty grains are highly resistant to both stored insect pests and fungi. Sometimes the dried earheads or threshed grain is stored in large containers above ground or in underground pits. The containers may be constructed of straw or sticks woven together and plastered with mud mixed with cowdung, or grain may be stored in large baked clay pots, bricks, concrete or sheet metal silos. There is an increasing tendency to keep the grain in cloth or gunny bags in storage rooms or buildings—particularly if the grain enters trade channels. Usually the store rooms or containers are kept tightly closed or in raised platforms to prevent rat damage. The capacity is usually up to 1.5 tons.

Underground pits, called *hagevu* in Karnataka (Iyengar, 1945-46), are pot or bottle-shaped excavations of varying sizes with a narrow top. These must be situated in well-drained, non-porous soils. The sides and bottom are firmly packed or rammed and lined with straw to prevent moisture from soaking the grain. The top opening is covered with a stone slab, covered with earth and firmly packed to assure a tight seal and obscure the location of the pit. The capacity of such pits can range up to ten tons and are intended for long-term storage. Ragi grain has been reported to have been successfully stored for up to fifty years in southern India.

Similar stores—usually above ground types—are utilized in Africa. However, storage of unthreshed earheads may be a more common practice in East Africa than in India. The application of insecticides to the stored grain is usually recommended if the intentions are to store the grain for longer than one or two years. Mixing of 0.1% lindane dust at the rate 227 g (8 oz) in 90 kg (200 lb) of grain; and/or 43 g (1.5 oz) of 1% lindane dust scattered over each bag of grain are recommended procedures.

Processing

Ragi grain may be consumed in a number of ways. It is sometimes roasted green—in the dough stage; the ripe, dry grain is cracked or ground into flour; or the whole grain is germinated to make a malt for direct consumption or for brewing.

Native Grinding Methods

Ragi grain is most frequently ground on flat or circular stones. The whole grain goes into the grinding process and therefore the flour contains most of the fiber making it hard to digest. Sometimes the grain is parched or roasted before grinding. In preparing malt, the seeds are germinated and then dried before grinding.

Milling

Studies on modern milling techniques were carried out by Kurien and Desikachar (1962). They found wet milling to be superior to dry milling in percent of flour extraction; but it resulted in lower retention of protein, calcium, phosphorus and thiamine as shown in the following table:

Constituent	Percent Extraction by Milling		
	Wet	Dry	Dry + Wet*
Total Yield	81	70	82.5
Protein	37	54	74.2
Calcium	14	45	49.5
Phosphorus	30	42	62.2
Thiamine	13	91	--

*Dry milling followed by wet milling of the processing residue.

The flour produced by different milling processes varied greatly in protein content (3.6–9.1%). Crude fiber was reduced from 2.6% to 0.19–0.57%; calcium from 0.36% to 0.13–0.27%. Generally, wet milling followed by wet processing of the residue was found most efficient. The same method of dry milling after heat conditioning (steaming for 2 minutes) has also been applied to the preparation of malted ragi flour to minimize the proportion of fiber.

Utilization

Many food preparations are made from ragi flour. In south India the flour is prepared in the cooked form as gruel, pudding, or soup (*ambli*); or baked into unleavened bread or cakes similar to the *idlies*, *dosais*, or *rotis* prepared from wheat, rice or other cereals. In making *ambli* or cold soup, the flour is soaked in water and fermented for about 12 hrs. It is then added to cracked rice, sorghum or millet flour being cooked in a separate container when the boiling stage is reached. After cooking well, it is cooled and eaten. Another preparation is roasting the green heads in the dough stage which are eaten with crude sugar (gur). In Africa, it is mainly consumed in the cooked form as porridge or used in brewing (Madras-DA, 1954; Iyengar, 1945–46; Dunbar, 1969).

Investigations on ragi malt have largely been carried out in India. Patwardhan and Narayana (1930) reported the enzymatic saccharifying power of ragi malt to be superior to that of sorghum and maize but not as good as that of barley malt. They also observed that optimum enzymatic activity occurred at temperatures between 55° and 60°C and pH 4.86 to pH 5.07. The ragi enzyme was more stable at higher temperatures than the sorghum enzyme. Sastri (1939) worked out a method for the preparation of malt under optimum conditions.

The enzymes of ragi malt were investigated by Chandrasekhara and Swaminathan (1953a, 1953b). They found that ungerminated seeds contained very little amylase, protease and phospharylase activity, but that activity was much increased by germination. Protease activity of malt increased from 0.36 to 1.86 mg/g of amino *N* as the period of germination increased from 24 hrs to 96 hrs of steeping. They also described a method for extracting proteolytic enzymes.

White ragi is particularly well suited for making malt. The use of white ragi for the industrial production of ragi malt was promoted in India. It had excellent keeping quality and was used in the preparation of farinaceous and invalid foods. In other regions, local malt of ordinary brown-seeded ragi was used in the preparation of a fermented drink called *bojah* or *bojali*, or brewed as beer in parts of Maharashtra State and the Himalayan foothills.

Chemical Composition

The chemical composition of ragi grain has been studied mainly in India and Africa. Superficially, it appears moderately low in fat (1.3%) and crude protein (6–8%); very high in calcium (8.3%) and potassium (0.41%); and moderately high in phosphorus (0.28% three-fourths phytin), iron (0.017%) and thiamine (0.42 mg/100 g). Its carbohydrate content ranges from 70–76% and it has a calorific value of 345 calories per 100 g or 98 cal/oz. The proportion of husk is intermediate at 5–13% by weight, but fiber content is high (3–4%) compared with rice and wheat (Aykroyd, *et al.*, 1963; Madras-DA, 1954; Iyengar *et al.*, 1945–46). Analyses of proximate principles reported by several investigators are reported in Appendix 10.

Seed Structure

The physical structures of the ragi seeds were studied and described by Winton and Winton (1932), while the chemical contents of the different parts of ragi grain were analyzed by Kurien, *et al.* (1959). The seed is irregularly globular or oval, 1.0 to 1.5 mm in diameter, and small, 300–450 seeds/g.

Physical Structure

The pericarp is papery and the surface of the seed is covered by small warts arranged in irregular longitudinal rows with the location of the embryo marked by a flattened or depressed area. Unlike other cereals, the spermoderm is strongly developed with the outer epiderm consisting of wavy-walled isodiometric red-brown cells with small warts in the middle, and arranged in irregular longitudinal rows. The cuticle has a finely granular surface. The inner epiderm is darker than its outer layer, an apparently wavy double layer.

The endosperm has a layer of small aleurone cells. The starch grains are similar but smaller than those of sorghum or maize and rarely exceed 20 microns in diameter. Polygonal cells occur in the outer horny portion while round grain occurs in the floury center. Aggregation is very limited. The embryo is comparatively large and the radicle extends outward from the somewhat long hypocotyl at nearly a right angle to the axis of the plumule.

Chemical Composition of Seed Fractions

The proportion of chemical constituents in different parts of the grain was studied by Kurien, *et al.* (1959). They found the husk consisting of 13.4% of the total weight of the grain to have 28% of the protein, 49% of the calcium, and 14% of the phosphorus. The endosperm comprising 81.3% of whole grain contained 37% of the protein, 14% of the calcium and 30% of the phosphorus. By subtraction then the embryo comprising only 5.3% of the total seed weight would have to contain all the fat (ca. 5%), 35% of the protein (2.46 mg/100 g), 37% of the calcium and 56% of the phosphorus. Presoaking the whole grain in 0.05 N HCl did not help release the nutrients in the husk and they suggested this may help explain the low apparent digestibility of ragi proteins and low calcium absorption reported earlier (See Appendix II).

Carbohydrates and Fats

The carbohydrates of ragi grain comprise about 70–76% of total grain weight at 12–13% moisture. The polysaccharides including starch are major constituents. In analysis of the carbohydrates of ragi grown at Tripolitania, Moruzzi (1931) obtained 61.8% starch, 7.94% cellulose, 0.80% reducing sugar, 0.54% dextrin and 4.85% pentosans. Other investigators have found higher starch contents—up to 66.2% and 1.2% reducing sugar. Das Gupta (1936) found ragi starch to be lower in viscosity than rice starch and that bleaching further reduced the viscosity. The defatted starch has a specific rotation of 203.0 and is suitable for use in the textile industry. The fats comprise about 1.5% of seed weight. There is no information on its composition, although Garg and Murti (1962) studied changes in lipids during germination. They had indications that saponifiable lipids are utilized in early germination while the unsaponifiable lipids undergo little transformation at first, but this increases in later stages.

Proteins

The protein content of ragi grain has been variously reported to range between 7 and 10% (Kadkol and Swaminathan, 1954; Johnson and Raymond, 1964). Nevertheless, considerable variation has been reported, presumably reflecting the effects of genotype and environment. Protein contents as low as 5.85% have been reported (Adrian and Jaquot, 1964); and as high as 14.2% (Iyengar *et al.*, 1945–46). It may be possible to influence protein level within a specific variety or genotype. Krishnamurthy (1968) obtained increases in protein content and decreases in calcium content with increases in nitrogen fertilizers from 20 up to 120 lb/acre at Bangalore, India. The varieties averaged 4.6% to 7.6% protein.

Genotype Effect

There is consideraole evidence for genotypic effects in protein content of ragi grains. Ramiah and Satyanarayana (1936) and Sastri (1939) showed wide differences in protein values and content. One strain, E.C. 1540—a white-seeded type—had up to 14.2% protein. In another comparative analysis, Kadkol and Swaminathan (1955) studied eight common ragi varieties and obtained the highest protein contents (and other nutritive values) in two white-seeded strains E.C. 4310 and 'Majjige', and lowest protein content in K-1, a brown-seeded type. Mahudeswaran, *et al.* (1966) compared seven white-seeded ragis with three brown types at Coimbatore, Tamil Nadu. They obtained protein levels of 7.89–8.76% in the browns and 9.01–11.60% in the white types, although the brown-seeded Co. 7 consistently yielded more grain. Similarly, Bates (1968) obtained 6.06% to 9.91% protein in ten brown-seeded strains compared with 11.44% protein in a blend of four white-seeded cultivars from the Indian collection (I.E.C. 807, 810, 821 and 822). The brown-seeded types with highest protein contents were I.E.C. 788 (9.94%), I.E.C. 775 (9.69%), I.E.C. 786 (9.44%) and I.E.C. 162 (8.93%).

The genetic variance for chemical constituents of ragi grain, including crude protein, fat, phosphorus, total ash and lime, was studied in nineteen ragi varieties by Kempanna and Kavallappa (1968). The variances were significant only for crude protein and fat contents, both of which have low broad-sense heritability estimates and low predicted genetic advance suggesting a strong influence of environment on these characters.

Types of Protein

The nitrogenous fraction of ragi flour was studied by Moruzzi (1931) who obtained a globulin containing 15.2% N, an albumin containing 16.1% N, and a prolamine containing 14.0% N. The albumin had properties similar to other albumins; but the prolamine (eleusinin) contained phosphorus and had a lower percentage of basic amino acids and a larger proportion of mono-amino acids than gliadin. Divakaran (1931) also examined eleusinin chemically and confirmed it as being characteristic of a prolamine and obtained the following nitrogen distribution:

Fraction	Percent of Total N
Humin-N	0.8
Amide-N	21.4
Dicarboxylic acid-N	22.5
Basic N	5.8
Arginine-N	2.2
Monoamino-Monocarbocylic acid-N	44.1
Non-amino-N	5.1

The proteins of ragi grain are difficult to extract. Narayana and Norris (1928) first isolated eleusinin by Van Slykes' method; but Niyogi, *et al.* (1934) could extract only about 60% of the total nitrogen using sodium chloride 4% solution, hot 70% alcohol, and dilute sodium hydroxide successively.

Amino Acids

There are several investigations on the essential amino acids in ragi grains which have utilized both chemical and microbiological assay methods. Analyses are presented in Appendix 12. Generally, ragi can be considered to have a well-balanced protein for a cereal grain. Of the four most essential amino acids the proportions of lysine ranged from 1.50 to 3.50% (av = 2.86%); tryptophan from 1.1 to 1.65% (av = 1.39%); methionine from 1.9 to 3.75% (av = 2.86%); and threonine from 2.08 to 4.3% (av = 3.06%). For eight different analyses, leucine averaged 8.62% and isoleucine 5.23% giving a leucine : isoleucine ratio of 1.65.

Cystine

Among the other amino acids, cystine was reported by Gayte-Sorbier, *et al.* (1960) as 2.6% for a total of 5.7% of the two sulfur-bearing amino acids, cystine and methionine. Desikachar and De (1947) also analyzed for cystine obtaining 1.83% of protein, which together with methionine (2.54%) totalled 4.37% sulfur-bearing amino acids or only slightly less than occurred in the rice and wheat samples analyzed concurrently.

Micro-Biological Estimates

Lal (1950) estimated six of the essential amino acids microbiologically using *Lactobacillus arabinosus* for tryptophan, *Leuconostoc meserteroides* for lysine, histidine, and phenylalanine; and *Streptococcus faecalis* for arginine and threonine. He was unable to account for the presence of threonine. However, subsequent analyses using both chemical and micro-biological means disproved this finding. Baptist (1951) showed whole ragi grain to possess more than 3.0% threonine, and Balasubramanian and Ramachandran (1957) using *Streptococcus faecalis* estimated threonine content to be 3.03–4.33%.

Subsequently, Taira (1965) reported values for 18 amino acids estimated microbiologically for ragi and oats. He found more alanine, aspartic acid, histidine, tyrosine, serine and threonine, and less cystine and basic amino acids in the prolamin of ragi than oats. For both grains, there was more glutamic acid, leucine, and proline; and less glycine, aspartic acid, lysine and arginine in the prolamin than in the other fractions.

Non-essential Amino Acids

Among the non-essential amino acids, Gayte-Sorbier, *et al.* (1960) gives the following percentages of protein: Aspartic acid = 6.5, serine = 5.1, glutamic acid = 20.3, proline = 7.0, glycine = 4.0, alanine = 6.2, and tyrosine = 3.6.

Minerals

The mineral content of ragi varies with genotype and environment. Total content of minerals ranged between 1.58 to 2.80%, according to Kadkol, *et al.* (1954). Fabriani (1939) reported 2.28% ash, while Adrian and Jacquot (1964) summarized the results of several investigators showing ash content ranging from 2.25 to 4.2% (See Appendix 10).

Ragi is exceptionally rich in calcium containing about 0.34% in the whole seed and ranging from 0.26 to 0.43% compared with

0.01 to 0.06% calcium found in many cereals. However, about half the calcium is retained in the outer husk and is not released by acid treatment (Kurien *et al.*, 1959). The phosphorus content runs slightly lower, from 0.2 to 0.32%, about 90% of which is in the form of phytin phosphorus (calcium magnesium salt or inositol phosphoric acid), according to Giri (1940). However, immature seeds contain a lower proportion of phytin than mature seeds.

The iron contents of ragi grain varies from 17.4 mg/100 g of whole seeds, about 3.0% of which is ionizable. Potassium is also very high at up to 408 mg/100 g of edible portion; and it is probably the richest source of iodine among the cereal grains, containing as much as 101 μg of I/100 g edible portion. Other minerals reported include: sulfur = 160–200 mg, zinc = 2 mg, copper = 0.59 mg, sodium = 11 mg, and chlorine = 44 mg per 100 g edible portion (Aykroyd *et al.*, 1963). Several trace elements have also been reported in *Eleusine coracana* from Cameroons by Busson (1965), including the following given in ppm: Ag = < 0.1, Al = 4, B = < 0.5, Ba = 22, Be = < 0.5, Bi = < 0.5, Co = < 0.1, Cr = 0.2, Cu = 5, Ga = < 0.1, Ge = < 1, Fe = 48, Li = 2, Mn = 19, Mo = 2, Ni = 0.2, Pb = 6, Rb = 2, Sn = < 0.1, Sr = 33, Ti = 0.3, V = 0.4, Zn = 15.

Vitamins

The grain of finger millet contains thiamine, riboflavin, nicotinic acid and choline. Platt (1962) reports the following average composition of vitamins in 100 g of ragi grain: thiamine = 300 mg, riboflavin = 10 mg, and nicotinamide = 1.4 mg. Passmore and Sundararajan (1941) determined the Vitamin B_1 or thiamine content of ragi was 420 μg/100 g and consumption of this millet should supply sufficient quantities of this vitamin to prevent beriberi. Goldberg and Thorp (1945) found somewhat less thiamine (averaging 167 μg per 100 g in South African varieties). Hoover and Jayasurinya (1953) estimated riboflavin content of ragi at 110 μg/100 g using *Lactobacillus casei.* This was slightly less than values obtained for maize flour (159 μg/100 g) and brown rice (140 μg/100 g).

Bhagwat, *et al.* (1944) suggested the presence of an anti-thiamine factor as they were unable to recover a considerable portion (83.7%) of the thiamine factor added to ragi and ragi extracts. However, Swaminathan, *et al.* (1950) later showed there was no anti-thiamine factor in ragi but that added thiamine was tenaciously retained and was not recovered by the thiochrome method, but can be recovered by treatment with lead acetate, and then digesting with pepsin.

Other vitamins of minor importance include choline reported by Dakshinamurthi (1955) to occur as choline chloride to the extent of 16 9 mg/100 g. Vitamin A is also present at 70 I.U./100 g (Aykroyd, *et al.*, 1963); or 0.037–0.090 mg per 100 g (Adrian and Jacquot, 1964).

Other Substances

Finger millet grain contains oxalic acid to the extent of 45.7 mg/100 g. The straw also contains very small amounts of hydrocyannic acid in comparison with that of sorghums (Brunnick, 1923–24). Considerably more serious are the toxins produced on improperly stored grain by a mold, *Heterosporium* sp., and perhaps a gram-negative bacterium. When eaten such grains cause vomiting and intestinal disorders (Narasimhan, 1929; Venkata-Rao, 1930).

NUTRITION INVESTIGATIONS

Diets based largely on cereals preferably supplemented with vegetable and animal proteins are normally considered superior to situations where the principal subsistence is from starchy root crops, plantains or similar energy sources. The incidence of kwashiokor was most prevalent in the Buganda region (Uganda) where most of the energy is derived from matoke bananas and the average protein consumption from all sources in 1959 was only 64.8 g/head/day, the lowest in Uganda. Protein consumption was highest in the Northern Province (117.4 g) and Eastern Province (121.9 g) where cereals like finger millet, sorghum, maize and pulses are major dietary staples.

There is some evidence that patients with *Diabetes mellitus* tolerate ragi better than rice, and that their blood and urine sugar levels tend to be lower. Peak blood sugar levels observed in normal patients were: rice = 150 mg/100 cc and ragi = 125 mg/100 cc; and in diabetic patients they were: rice = 470 mg/100 cc, ragi = 400 mg/100 cc (Ramanathan and Gopalan, 1956).

Vitamin Availability

Complete dependence on cereals may not necessarily result in protein deficiency symptoms, but vitamins are often inadequate in such diets. In the case of millet, Corkill (1934) reported a condition referred to as pellagra among an Arab community (chiefly women) in the Butara Desert of Sudan, that occurred mainly in the hot, dry season when millet constituted nearly the complete diet. The disease did not appear in other seasons when the millet is supplemented by milk. The author hypothesized deficiencies of Vitamins A and D, cholesterol, and good quality proteins as causative factors. Although Vitamin A deficiency was implicated in these investigations, ragi does contain a small amount (70 I.U./100 g), and Moruzzi (1938) was able to restore normal growth in rats previously depleted of Vitamin A by adding five grams of dry ragi grain to their diet.

In later investigations Corkill *et al.* (1948a, 1948b) made some interesting studies on prisoners of war in the Sudan where diets of millet were supplemented by meat, millet beer, groundnuts, and/or marmite. At the outset deficiencies of vitamins were widely evident and included a 5% incidence of pellagra and scurvy, some beriberi and symptoms of riboflavin deficiency. Those prisoners receiving eight ounces of meat per day appeared to have adequate minimal supplementation, but when the diets of groups of ambulatory patients received various supplements, it was discovered that a millet diet supplemented with two to three ounces of groundnuts and two to four pints of millet beer daily prevented the occurrence of pellagra, beriberi and scurvy.

Calcium and Phosphorus from Ragi

Ragi is a very rich source of calcium (300 mg/100 g) and also has a good amount of phosphorus (283 mg/100g). Ranganathan (1935) studied the utilization of these two elements in rats and reported that only 42.6% of calcium and 42.4% of phosphorus are retained by the rat. In other studies Giri (1940) found calcium from ragi was less available (68%) than the Ca from Pennisetum millet (89%) and sorghum (84%) when these cereals were fed at the 70% of diet level. Similarly, the phosphorus availability was 58% for ragi, 74% for Pennisetum and 67% for sorghum. However, ragi has a much higher content of calcium than other cereals and when fed at the 30% of diet level, the Ca availability rose to 86%.

Investigations of mineral availability in ragi has also been carried out with human subjects. Subramanyan, *et al.* (1955) found calcium retention to be comparatively low in young male adults (22–32 years), being only 10% (98 mg) of a 3,383 mg intake level, while the average daily absorption of phosphorus from the ragi diet was only 510 mg or 22% of intake. The excess of calcium in the gut tending to precipitate the phosphorus as calcium phosphate was suggested as an explanation for these results.

In other studies with young girls aged 9–10 years, Joseph, *et al.* (1958, 1959a, 1959b) obtained 20% retention of calcium (226 mg) and 15% retention of phosphorus (135.2 mg) on a complete ragi diet of 280 g plus supplements per day. When the ragi diet was replaced by different proportions of rice (25, 50, 75 or 100%) the retention of calcium decreased from 226 mg to 52 mg and phosphorus retention fluctuated between 117 and 165 mg. However, all subjects maintained positive balances of nitrogen, calcium and phosphorus. The authors suggested that replacement of rice by up to 25% ragi in a poor vegetarian diet would help in making up the calcium deficiency without adversely affecting the nitrogen balance.

Protein Efficiency

The biological value (BV) and digestibility coefficient (DC) of ragi proteins were studied in rat feeding trials by several workers. Niyogi, *et al.* (1934) obtained values of BV = 90.5% and DC = 77.5% feeding ragi at the 5% level of protein intake; while Swaminathan (1938) obtained similar values of BV = 89% and DC = 80% feeding rats at the same (5%) protein level, but found the protein efficiency ratio (PER) to be only 8.71 at the 5% protein intake level. It was therefore concluded that ragi proteins at 5% level were efficient for maintaining adult rats, but not efficient in supporting growth of young rats. However, when supplemented by pulses and skim milk powder, ragi proteins were quite efficient in supporting growth in young rats. Parching of ragi grains was found to increase the biological value and lower the digestibility coefficient to a slight extent (Kurien *et al.*, 1960).

Biological value is also influenced by genotype. Ramiah and Satyanarayana (1936) found white ragi to have a protein BV of

91.5% and, therefore, superior to that of the brown-seeded types. Nevertheless, people accustomed to the apparently stronger flavor and better quality beer may prefer the brown-seeded strains (Johnson, 1968). Moreover, white-seeded strains may be more susceptible to bird attack and possibly insect infestation in storage.

Ragi protein efficiencies have also been investigated with poultry and in human subjects. Mukherjee and Parthasarathy (1948) fed adult cockerels with five cereals and assessed retention of nitrogen. They found Pennisetum millet to possess the highest protein value, followed by ragi and barley, with sorghum and proso (Panicum) millet poorest in protein quality. In human subjects Subramanyan (1955) studied nitrogen intake and retention in adult males consuming a poor ragi diet and observed daily ingestion to be 10.6 g and retention 1.1 g with 5.5 g of nitrogen excreted in the feces for an apparent protein digestibility of 50%.

Other investigations were carried out with young girls, 9 - 10 years of age, consuming diets consisting of 280 g daily of all ragi, different proportions of ragi and rice, and all rice by Joseph, *et al.* (1959b). They observed daily intakes of 4.41 g - 4.51 g of nitrogen (28 g of protein), retentions of 0.52 g, 0.89 g, 1.19 g and 1.48 g for apparent coefficients of digestibility of 53, 64, 67 and 71% as the ragi diet was replaced by 50, 75 or 100% rice, respectively. As previously noted, ragi added to rice greatly increased calcium intake and retention. Therefore, the author concluded that poor rice diets could be improved by replacement with up to one-fourth part of ragi. Kurien, *et al.* (1959) attributed the poor absorption of proteins from ragi as resulting from the excessive content of roughages—principally cellulose and hemicelluloses. The husk which constitutes only 13.4% of total grain weight contains 28% of the protein (30% non-extractable) and half the calcium.

Blending Ragi with Other Cereals

Blends of cereals like rice and ragi frequently produced better growth rates than diets of rice alone. One of the early experiments in this line was reported by Mason, *et al.* (1946). They blended ragi (up to one-third of the ration) and butter (up to 0.8 g daily) separately and together with rice. They observed a marked stimulating effect of the ragi on growth, but a depressing effect of the butter. When both were included they tended to cancel each other out. Later Kurien, *et al.* (1958, 1960) observed average weekly increases in rat body weights of 6–9 g on ragi diets compared with 4–6 g on rice diets. Replacement of rice by ragi to the extent of 25% or more increased growth rates (2.5 × control), fresh liver weights, red blood cells, haemoglobin and serum proteins in rats. The improved growth rates were attributed primarily to higher calcium content of ragi. There were no significant increases above 25% ragi level.

Supplementing Ragi Diets

Investigations on supplementing poor vegetarian diets based on ragi have been carried out in India. Major emphasis has been given to improving the quality and content of protein in the diet. Leela, *et al.* (1965) fed ragi to Wistar weanling rats at the 6% protein level with and without supplements of L-lysine, DL-threonine or 10% skimmed milk to simulate the quality of egg proteins. The PER of unsupplemented ragi at 0.95–1.12 was significantly increased by supplementation of lysine to 2.08–2.19, or with lysine and threonine to 3.04–3.12. Content of liver fat was reduced when supplemented by lysine and threonine. However, a ragi diet fed at the eight percent protein level (about average for dry grain) had a PER of 2.1.

Daniel, *et al.* (1967) carried out similar experiments supplementing ragi and maize with various mixtures of oilseed meals, Bengal gram and skim milk, in investigations of low-cost, balanced vegetarian diets. The mixtures (with oilseeds and Bengal gram) contained 17–20% protein and had PER's of 2.01–2.63, while fortification with lysine and methionine increased PER's to 2.38–3.28 compared with 3.40–3.59 obtained for skim milk powder. In further studies, Daniel, *et al.* (1968a, 1968b) increased the mean weekly growth rate of rats on a poor ragi diet by supplementation with 15–18% coconut meal, 15 16% Bengal or red gram, 6.0% soybean meal or 9% skim milk to provide about 2.5% extra protein. Ragi alone produced mean weekly growth rates of 9.3 g; ragi supplemented by vitamins and minerals was slightly better at 10.4 g, but with grams, soybeans and skim milk it increased to 18.8–20.1 g, 20.3 g and 21.0 g, respectively. This was somewhat better than similar diets based on sorghum but slightly inferior to those of Pennisetum millet.

Supplementation of ragi diets with various other protein sources has been reported by several investigators. Subramanyan, *et al.* (1945) obtained significant increases in rat growth by adding a cottonseed meal extracted from whole kernels with boiling absolute alcohol. Venkatrao, *et al.* (1958) showed increased growth response in rats by adding up to 20% low-fat groundnut flour to ragi and sorghum diets. Tasker, *et al.* (1964) added a supplement containing coconut meal, Bengal gram flour and groundnut meal in the ratio of 1 : 1 :2 at the 12.5% level together with minerals and vitamins to diets of wheat, maize, sorghum and ragi. The supplement significantly increased growth rates of weanling rats in all diets from 5.6–10.2 g/week without supplement up to 14.2–15.9 g with supplement.

A specific blend useful for supplementing poor vegetarian diets and called 'Indian Multipurpose Food' was described by Kuppuswamy (1957). This consisted of a blend of 75 parts of low-fat groundnut flour and 25 parts of roasted Bengal gram flour and fortified with calcium and essential vitamins. The recommended level of supplementation was 12.5% for wheat, rice, ragi and sorghum diets. Subsequently, several blends of Bengal gram and low fat groundnut, soybean and sesame flours added to ragi diets to increase the protein level of the diet by 2.5%, produced highly significant increases in growth rates of rats (Guttikar *et al.*, 1968).

Refining Ragi Flour

Milling and refining ragi flour and the effect on its nutritional values has been studied at the Central Food Technology Research Institute at Mysore, India. Kurien and Desikachar (1962) compared (1) wet milling, (2) dry milling, and (3) dry milling with wet milling of the residue. They obtained the lowest total yield (70%) from dry milling with intermediate retention of protein (54%), calcium (45%), phosphorus (42%) and thiamine (91%). The dry milling combined with wet milling of the residue resulted in highest yield of flour (82.5%), and best retention of protein (74.2%), calcium (49.5%) and phosphorus (62.2%).

Feeding refined versus whole ragi flour to children was reported by Kurien and Doraiswamy (1967). The same diet was fed to rats by Kurien (1967). No significant differences were observed in the height, weight, nutritional status or red blood cell and haemoglobin content of children who were fed the two alternate diets for five and a half months. However, there was a significant increase in the apparent digestibility of the protein from the refined ragi flour. Conversely, with rats the refining process adversely affected the growth promoting value of ragi flour, although calcium availability from the refined flour was significantly higher than in the whole grain flour. The growth promoting factor was partially restored and calcium availability further increased by adding the wet-processed flour fraction from the dry milled residue to make up a 'composite' flour.

Ragi Malt

Good quality malt can be prepared from ragi grain—particularly the white-seeded types. It is prepared by steeping the grain in running water, couching the seeds for germination for 72 hrs at temperatures between 23° and 25°C, drying and removing the vegetative portion, and finally grinding to make a flour (Sastry, 1938). The diastatic activity of ragi malt was found to be less than that of barley (Niyogi *et al.*, 1934). According to Chandrasekhara, *et al.* (1953), a better yield of extract was obtained when ragi malt was mashed with an equal quantity of gelatinized wheat or sorghum flour. The projected costs for commercial malt extract production in India was found to be Rs. 1.00/pound for extract with 80% solids (Chandrasekhara, *et al.* 1959). The commercially prepared product was marketed under the name 'Ragotine'.

The enzymes present in ungerminated and germinated ragi were investigated by Chandrasekhara and Swaminathan (1953a, 1953b, 1954). They found that ungerminated ragi possessed very little amylase, protease and phosphatase activity, but that activity of these enzymes increased considerably when the grain was germinated. The preparation of a good quality malt possessing an agreeable flavor is suitable for infant and invalid foods and Chandrasekhara *et al.* (1957) described a nutritionally balanced preparation as a supplement to the diet of weaned children. This included a blend of ragi malt flour, skim milk powder and puffed Bengal gram flour and fortified with minerals and vitamins.

Ragi in Animal Feedstuffs

Very few investigations on utilizing ragi in poultry and large animal feeding rations have been reported. In Rhodesia, ragi was fed to fattener pigs in combination with maize (75% millet + 25% maize) or pollards (70% millet + 30% pollards) and compared with maize : pollard blend (60 : 40). The protein contents were 15.5%, 18.4% and 17.2%, respectively (Calder, 1960; 1961). When 25% of the maize was replaced by millet, there was a small improvement in efficiency of feed conversion over maize alone or maize + pollards. However, the millet/pollards combination was less efficiently used than maize alone. Adding 25% millet to the maize did not materially affect the carcasses. In an earlier experiment, the ragi varieties, Rupoka (6.7% protein) and Munga (9.9% protein), were fed with maize (3 parts millet : 1 part maize) to fatteners. The Munga cultivar produced better growth and conversion of feed than Rupoka, but there was no significant difference in carcass quality, nor did the Rupoka have an adverse effect on sows during pregnancy or lactation.

The use of ragi in poultry rations was investigated in India (Ayyaluswami *et al.*, 1967). They fattened white leghorn chickens to eight weeks of age on diets of 23% crude protein with similar energy levels from (1) maize 45%, (2) ragi 45%, (3) maize 25%, and (4) ragi 20%. Average gains ranged from 463–488 g in the first trial and 443–514 g in the second trial, but the differences were statistically insignificant. Feed per gram of gain ranged from 2.55 to 2.77 g in the first trial and from 2.70 to 3.01 g in the second trial.

Ragi Straw Quality

Young ragi plants are tender and green and appear to be highly palatable judging from the preferences of wild rabbits and untended cattle. Nevertheless, it does contain some hydrocyannic acid, although in very small amounts (Brunnich, 1923–24). However, the dry straw from mature plants varies widely in its composition according to Sen and Ramiah (1938):

	Percent
Moisture	9.88
Ash	12.10
Crude protein	2.19
Fat	2.37
Fiber	28.22
Carbohydrates	44.88

In regions of India where ragi is a prominent dryland crop, the straw is considered of excellent quality and carefully preserved. It apparently improves on keeping—possibly by fermenting. When properly conserved, it remains edible for as long as five years even though stacked in the open. However, irrigated ragi straw tends to become coarse and may be used for other purposes such as fuel, thatching, bedding for cattle, or simply plowed down as organic matter (Iyengar *et al.*, 1945–46).

Ragi straw was compared with that from Pennisetum millet, Paspalum millet, wheat, rice and sorghum in feeding tests with eight-year old bullocks by Patel, *et al.* (1961). They found ragi straw to have the highest proportion of total digestible nutrients, 60.8%, compared with 50 to 57% TDN for the other species. However, all the fodders produced negative nitrogen balance in the animals, and all except wheat straw gave negative calcium and phosphorus balances.

The possibility of improving the quality of ragi straw by fertilizing the growing crop with organic manure and superphosphate was explored by Ramulu and Mariakulandai (1964). They were successful in obtaining moderate increases in nitrogen and phosphate contents. Earlier, Warth, *et al.* (1932) had studied the feasibility of direct supplementation of ragi fodder with calcium phosphate. They concluded that unsupplemented ragi has sufficient calcium but is borderline for phosphorus in ruminant nutrition. However, they also increased calcium assimilation by the addition of calcium phosphate suggesting that phosphoric acid influences lime assimilation.

Decomposition of ragi straw under different conditions of fermentation was investigated by Shrikhande (1936). Strong acidity under partially aerobic and anerobic conditions prevented the production of mucus and stickiness during fermentation. The carbon/nitrogen ratios were varied by adding different sources of nitrogen, and wide C/N ratios produced greater loss than narrow C/N ratios. However, high levels of nitrogen or adjusting the pH to 9.0 with sodium carbonate appeared to have no effect on the stickiness occurring during fermentation.

TRADE AND MARKETING

There is very little foreign trade in ragi grain, although Iyengar, *et al.* (1945–46) mentioned that India did export a small quantity to Malaysia in normal seasons. Within India there is very little internal movement of the grain between the states except between Karnataka and adjoining districts in Tamil Nadu and Maharashtra. However, in famine years like 1965 there was some movement of bulk grain lots from Bihar, West Bengal and Orissa into the drought-stricken, high ragi-consuming areas of Karnataka and Tamil Nadu.

Most of the ragi crop in both India and Africa is consumed within the region where it is produced. Nevertheless, the crop does have industrial possibilities through its malt and brewing potentialities. The market price of ragi grain in India has increased very considerably (along with other cereals) over the past 25 years when its price ranged between Rs. 5.00 to 7.50/quintal. During periods of severe famine in the mid-1960's, it often sold for more than Rs. 100/quintal. It is also bartered extensively for labor and livestock.

CONCLUSIONS ON THE RAGI PRODUCT

Ragi has some unique qualities which make it a potentially valuable product. It has excellent malting qualities with considerable industrial potential for producing malt extract and for brewing. Moreover, the yielding potential of ragi is the highest among the minor millets. A particularly important feature in the humid tropics is the excellent keeping quality of ragi grain—the best of all the cereals.

The most important aspect of ragi grain is its quality as a food. It is an excellent source of calcium (seven times more than rice), and also has good amounts of phosphorus. However, its major asset may well be the excellent quality of its protein. Among cereals, it has a relatively favorable amino acid spectrum. In particular, it possesses a reasonably high level of methionine—the major limiting amino acid of certain tropical regions, and the component least correctable by the addition of pulses to the diet. The low total protein in ragi is a matter for concern, but there appears to be much scope for improvement through breeding and fertilization. An unpublished experiment conducted at Makerere University in 1969 indicated that protein levels could be increased by more than 75% simply by increasing nitrogen fertility levels. Preliminary studies on different genotypes at Serere Research Station have given similar results.

Fiber is reasonably high in ragi grain—a quality appreciated for its slower digestibility and sustaining power by certain laborers and peasant farmers. However, this quality hardly makes it attractive to persons engaged in sedentary occupations or those accustomed to more easily digested cereals like rice. Of course, it is possible to regulate fiber content by milling and perhaps even by breeding. The first step in the latter approach would be to screen the World Collection for fiber content.

There is virtually no information on the genotype effect on malting qualities in the ragi grain. It is highly likely that diastatic power and other malting qualities are genetically controlled and also influenced by environment, as in barley. An approach to exploiting this potential by breeding should begin by examining the World Collection for characters like diastatic power.

An examination of the several desirable features of ragi suggest an important role in contributing to future nutritional needs. The possibility of using ragi as a famine food is indicated by virtue of its good storability, productivity and nutritional values. A further dimension is the industrial possibilities for malting, brewing, starch making and animal feeds. However, these potentialities will only be realized when there is wider recognition of ragi as a very useful commodity and there is better support for programs of research and improvement.

APPENDICES

APPENDIX 1. SYNONYMS AND VERNACULAR NAMES FOR *Eleusine coracana* Gaertn. (After Iyengar *et al.*, 1945-46; Porteres, 1958; Jacques-Felix, 1961; and Adrian and Jacquot, 1964)

Region and/or Language		Vernacular Names
English:		Ragi (I)
		Finger Millet
		Birdsfoot Millet
		African Millet
		Coracan Millet
		South Indian Millet
		African Millet
		Kurukkan
India:		Raghi
		Chari
		Bhav
		Tanudelu
		Mandal
		Okra
		Mandia
		Chollu
	Bengal	Marua
	Gujarat	Bavto
	Himalayas	Koda
		Kondon
		Kodra
		Kutra
	Hindi	Mandua
		Marua
		Ragee
	Kannada	Ragi
	Malayalam	Muttari
	Marathi	Nachni
		Nachri
		Nagli
	Punjab	Chalodra
		Mundal
	Sanskrit	Raga
		Ragi
		Rajika

APPENDIX 1 (*contd.*)

Region and/or Language		Vernacular Names
	Santal	Kode
	Sind	Nachni Nangli
	Singhali	Kurukkan
	Tamil	Kapai
		Kaver
		Kervaragu
	Telugu	Chodalu
		Ragulu
		Sodee
		Soloo
		Tamidelu
	Tulu	Ragi
	U.P. and Bihar	Makra
		Nanguli
		Rotka
	Oriya	Mandiya
Burma:		Satni
French:		Coracan
		Mil Rouge
		Sorgho
		Zorgzaad
		Durra
		Mohrhirse
		Saggina
		Dari
		Eleusine gierst
		Africanski hirse
		Ragi darisi
East and South Africa:		
	Rhodesia	Poko
		Phoko
	Lake Victoria & Mount Elgon	baga
		baiyna
	Bantu	Luco
		luho
		luku

APPENDIX I (*contd.*)

Region and/or Language		Vernacular Names
West Africa:		
	Nigeria	little chargari
		sarga (Dalziel)
	Cameroun	tiagari
	Maroua	dudo (Malzy)
		tidendari
		tantari
		gawri
		gari
		Shar-, sar-, tiar-, sara
Upper Nile: (Eastern Sudan)		
	Haut-Nil	Ooliezei (Thompson)
		Ulezi (Sacleux)
		Ulese (Sterling)
	Uganda	bolu (Dawe)
		Bulo
		U-buro (Pages)
		Bantu bemba amale (Richards)
		Otulo (Purseglove)
	Bantu Kitabwa	bulo
		bule (male)
		amaro
		uwuro
		ubwuro
		uruheke
		urugenyo
		Kugenya
		hugesa
	Kenya	Wimbi (Shantz)
		Uwimbi
		U-lese (Sperling)
		Uimbi
		Uimbe
		nar-umbi ([illegible]t)
		Njetj-imbo (Junker)
		Uwimbai (Sacleux)

Appendix 1 (*contd.*)

Region and/or Language		Vernacular Names
	Tanzania	mpege mbega (Holst) imbeyu (plural dimbeyu) mbe mbegu nivegu
	Rhodesia	rapoko upoko (Wood)
Africa:		talabun dakussa tucusso murwa dagusa rapoko rupoko mijo africano besna
Thailand:		Phak khouay
China:		Ts'au-tzu

APPENDIX 2. DISTINGUISHING CHARACTERISTICS OF *Eleusine indica* AND *E. africana* (after Kennedy-O'Byrne, 1957)

Chromosomes	*Eleusine indica* (2n = 18)	*Eleusine africana* (2n = 36)
Height of Plant	(8–) 30–45 (–90) cm	(15–) 30–90 cm
Basal internode of culm	slender, rarely more than 5 cm long×3.5 mm wide	stouter, longer, up to 18 cm long×7.0 mm wide
Leaf-blade	shorter, up to 17 cm long×4 mm wide	longer, up to 50 cm long×1.0 mm wide
Spike	0.5–1.0 mm	1.5–2.0 mm
Spikelet	4–5 mm long×2–2.5 mm wide	6–7.5 mm long×3–4 mm wide
Florets (number per spikelet)	(3–) 4–5 (–6)	(3–) 4–6
Lower glume	(1.5–) 1.8–2.3 (–2.5) mm long, narrowly oblong in profile, oblong to an obtuse apex when opened out, obscurely winged on the keel, 1-nerved.	(2–) 2.5–3.0 (–4.0) mm long, narrowly lanceolate-oblong in profile lanceolate-oblong to an acute shortly bifid apex when opened out, broadly winged on the keel, 1-3-nerved
Upper glume	2.0–2.5 (–3.2) mm long, oblong in profile, elliptic to a shortly mucronate apex when opened out	(3.5) 4.0–5.0 (–5.2) mm long, lanceolate-oblong in profile, elliptic-oblong to a mucronate apex when opened out
Lemma	2.7–3.0 (–3.5) mm long, obliquely lanceolate-oblong in profile, ovate-lanceolate to an acute apex when	(3.5) 4.0–5.0 mm long, obliquely lanceolate in profile, ovate-oblong to an obtuse apex when opened out, 1-nerved or

APPENDIX 2 (*contd.*)

Chromosomes	*Eleusine indica* (2n = 18)	*Eleusine africana* (2n = 36)
	opened out, 1-nerved or obscurely 3-nerved	usually obscurely 5-nerved
Palea	2.0–2.5 mm long×0.8 mm wide, lanceolate-oblong between the keels when flattened, with obscure wings along the keels	3.0–4.0 mm long×1.2 mm wide, elliptic-lanceolate between the keels when flattened, with conspicuous wings along the keels
Lodicules	0.25 mm long×0.25 mm wide	usually twice as large
Ovary	0.5 mm long	1.0 mm long
Anthers	0.5–0.75 mm long	0.8–1.0 mm long
Fruit	1.6–1.8 mm long× 0.5–0.8 mm wide	2.0 mm long ×1–1.3 mm wide
Seed	1–1.3 mm long×0.5 mm wide, lanceolate, acute at base and apex	1.3–1.5 mm long×0.8 mm wide, ovate-oblong, truncate at base and apex

APPENDIX 3. GEOGRAPHICAL DISTRIBUTION, ALTITUDINAL RANGE AND HABITAT OF *Eleusine indica* AND *E. africana* (after Kennedy-O'Byrne, 1957)

	Eleusine indica	*Eleusine africana*
World Distribution	Widespread throughout the tropical regions of the world, established in warm temperate areas and occurring as an adventive as far north as the British Isles and south as far as New Zealand, extending approximately from latitudes 55°N to 45°S	Recently found as an adventive in the British Isles (introduced with wool from South Africa) and Sweden; otherwise no known distribution outside of Africa.
African Distribution	Within the limits of the tropics from the Cape Verde Islands, through the territories of N.W. Tropical Africa, French Sudan and Niger Colony and the countries of the Guinea coast, eastwards to the southern part of the Sudan and south to Angola, Bechuanaland, S. Rhodesia and Portugese East Africa to the Tropic of Capricorn.	Extending from within the the tropics through the territories of N.W. Tropical Africa, eastwards to the territories of N.E. Tropical Africa (Sudan, Eritrea, Somaliland and Abyssinia, and south to Cape Peninsula in the Union of South Africa.
Altitudinal Range	Occurring within a lower range, extending from sea level up to about 5,000 ft. (infrequently up to 6,000 ft.)	Occurring within a higher range, usually extending from 3,000 ft. (infrequently from as low as 1,000 ft.) up to 7,000 ft.
Habitat	A wayside weed, along roads and paths, and around settlements and native habitations.	A weed of cultivations and along waysides. In Uganda, usually found as a weed in fields of *Eleusine coracana* where it occurs in certain seasons in great abundance and seriously reduces the yield of the cereal crop.

Appendix 4. Distinguishing Characteristics of *Eleusine indica* and *E. coracana* (after Porteres, 1951)

	E. indica	*E. coracana*
Height of culms	10–75 cm	30–150 cm
Vigor	relatively weak	very vigorous
Opening of sheath	subglabrous	pilous
Ligule	long-fimbrillate (fringed)	short-fimbrillate
Blade	somewhat wide	wide and longer
Heads	fine, somewhat compressed, not bent	thick, generally erect, then bent
Solitary heads under the umbel	very common	occasionally
Secondary axis	disjointing itself from the glumes	not disjointing at all
Spikelets at maturity	caducous or deciduous	not caducous
Glumes	glabrous, obtuse	scabrous, sub-pointed
Palea	pointed and lanceolate, oblong in profile	obtuse and obliquely oval in profile
Caryopsis	trigonal and rugose, shatters readily	globulo-ovoid and finely covered with lines and fine stripes, often difficult to separate from glumes
Habit	uneven, pantropical	cultivated

APPENDIX 5. RANGE OF VARIABILITY FOR SOME BOTANICAL CHARACTERS IN THE INDIAN *E. corac.. a* COLLECTIONS (after Srinivasan *et al.*, 1965)

Source of Collection	Total No. of cultures grown	Plant height (cm)	No. of basal tillers plant	No of ears per plant	No. of digits per main ear	Length of longest finger (cm)	Weight of main ear (gm)
Andhra Pradesh	38	45-144	1-16	1-30	2-16	3-13	0.2-1.15
West Bengal	39	33-105	1-15	1-24	4-12	3-15.5	0.3-8.0
Bihar	182	22-145	1-21	1-60	2-59	2-1.5	0.2-12.5
Gujarat	18	100-108	4-12	14-41	4-10	6-8	3.2-9.2
Kerala	25	51-113	1-13	2-36	3-8	4.5-8.5	0.9-9.6
Madhya Pradesh	47	33-104	1-10	1-13	4-10	3.3-9.0	0.1-7.3
Tamil Nadu	60	40-137	1-32	2-50	2-15	3-12	0.3-12.5
Karnataka	76	35-135	1-20	1-35	2-15	3.5-11.5	0.2-13.7
Orissa	72	16-130	1-19	1-70	2-9	3.3-15.0	0.3-9.4
Punjab	14	71-107	4-19	15-37	—	—	—
Uttar Pradesh	80	28-96	1-20	1-45	3-18	3.5-10	0.3-8.2
NEFA, Assam & Manipur	19	28-92	1-6	1-6	2-8	4.5-7.2	0.3-3.8
		16-145	1-32	1-70	2-57	2.0-15.5	0.2-13.7

Appendix 6. Botanical and Agronomical Characteristics of Five Fertility-Responsive *E. coracana*. Collections (after Srinivasan *et al.*, 1965)

I.E. No. and Origin	Mean height (cm)	Mean no. of basal tillers	Mean no. of ears	Mean no. of thumbs	Mean no. of fingers	Mean length of longest finger (cm)
5 (Andhra Pradesh)	105.8	11.1	11.4	1.1	6.3	4.9
27 (—do—)	84.3	12.2	12.3	1.1	4.4	5.0
28 (—do—)	76.8	5.5	7.7	2.1	6.0	4.4
267 (Gujarat)	103.3	9.0	27.9	1.0	6.6	6.8
378 (Tamil Nadu)	86.8	11.1	10.9	2.0	7.7	5.6

I.E. No. and Origin	Weight of main ear (gm)	Grain yield per line (kg)	Lodging	Maturity group	Number of days to 50% flowering
5 (Andhra Pradesh)	5.9	1.04	Resistant	Medium	69
27 (—do—)	3.7	1.18	Resistant	Medium	74
28 (—do—)	5.0	1.35	Resistant	Early	52
267 (Gujarat)	5.3	1.19	Susceptible	Medium	76
378 (Tamil Nadu)	7.1	1.04	Resistant	Medium	70

Appendix 7. Means and Variances of Seven Characters for 162 South Indian *E. coracana* Collections (after Srinivasan *et al.*, 1965)

Character	Andhra Pradesh		Tamil Nadu		Karnataka	
	Mean	Variance	Mean	Variance	Mean	Variance
No. of ears per plant	7.6	7.24	9.4	16.15	7.2	8.47
No. of digits on main ear	7.0	2.06	6.3	0.76	6.3	1.06
Plant height (cm)	99.1	136.66	100.6	110.34	98.7	139.75
Days to flowering	74.7	63.45	78.0	113.17	84.7	54.39
No. of basal tillers	4.2	2.79	5.8	4.79	4.8	4.08
Length of finger (cm)	6.7	1.92	7.1	31.18	7.1	1.18
Weight of main ear (gm)	4.4	1.09	4.9	1.36	4.0	1.15
No. of lines	38		59		65	

APPENDIX 8. DESCRIPTIONS OF INDIGENOUS RAGI CULTIVARS OF KARNATAKA (after Coleman, 1920)

Variety	Description-Pure Strains	Average Yield Grain	Straw lb/acre
1. Hullubile	Green glumes—open spikes	1,025	1,392
2. Karegidda	Violet glumes—incurved	796	1,245
3. Gidda	Violet glumes—incurved	834	1,322
4. Hasarukambi	Green glumes—open spikes	900	1,408
5. Madayyana-giri-I	Violet glumes—open spikes	863	1,378
6. Madayyana-giri-II	Green glumes—open spikes	863	1,285
7. Dodda	Green glumes—open spikes	844	1,320
8. Guoubile	Green glumes—incurved	847	1,428
9. Majjige	Light green glumes—open spikes	577	1,157
10. Majjige-Ing.	Light green glumes—open spikes	587	1,417
11. Jenumudda	Green glumes—open spikes	938	1,598
12. Rudrajade	Green glumes—branched spikes	538	957
13. Jadesanga	Violet glumes—branched spikes	981	1,256

APPENDIX 9a. DESCRIPTIONS OF THE IMPROVED STRAINS OF *Eleusine coracana* Gaertn. IN ASIA AND AFRICA

State and station	Strain	Sowing season	Approximate duration (days)	Grain yield adapted region lb/acre	Remarks
Andhra Pradesh	AKP 1 & 2	May to August	—	—	'Punasa' ragi strain (monsoon)
(Anakapalle)	AKP 3, 4 & 5	Dec. to April	—	—	'Pyru' ragi strain (cool weather)
	AKP 6 & 7	Aug. to Dec.			'Pedda Panta' strain
(Hagari, Karnataka)	H-1 (or R-43)	(1) Main Season—Aug. to Dec. (2) HW—Jan. to May	—	—	Close-fisted type
	NR 124	—do—			
	NR 25G-1-2	May to Aug.	—	—	'Punasa' strain
Maharashtra	Nagli-11	*Kharif*—June-July to Oct.-Dec.	135	950	
	Nagli-31		145	1,000	
	Nagli-16		150	1,050	
Coimbatore	Co. 1	(1) May-June to Sept.-Oct. (2) Dec. to March	120	900 (rain) 2,000	Selection from Gidda Aryan of Salem
	Co. 2	—do—	110	(IRR) 2,000	Selected from multi ragi of Coimbatore
	Co. 3	(1) May to Sep. (2) Dec. to March	110	2,200 (IRR)	Mutant from Co. 1 popular in Coimbatore and

APPENDIX 9a (*contd.*)

State and station	Strain	Sowing season	Approximate duration (days)	Grain yield adapted region lb/acre	Remarks
					Chingleput and North Arcot
	Co. 4	May-June to Sept.-Oct.	130-140	800 2,200 (IRR)	Selected from pollidam local for Ramanathapura, Tirunelide
Uganda	Engenyi	March to July	110	2,700	EAAFRO selections
	Serere 1	—do—	105	2,800	—do—
	Gulu E	—do—	110	2,900	—do—

J. IMPROVED VARIETIES RECOMMENDED FOR THE MAJOR RAGI GROWING STATES OF INDIA

	Variety Recommended	Remarks
rnataka	Ragi 1 (Kar)	For sowing in April-May; rainfed as well as irrigated
	Ragi 5 (Kar)	Mysore and Hassan districts
	Ragi 22 (Hain)	For July sowing
	Ragi 10 (Hain)	For sowing in July, August in Tumkur and Kolar districts
	H-1	Bellary district
Tamil Nadu	Co. 1	Irrigated or rainfed in Salem district
	Co. 2	Under irrigation in Coimbatore district
	Co. 3	As dry crop in Coimbatore, Chingleput and North Arcot
	Co. 4	Suitable for Ramanathapuram and Tirunelaveli districts
Andhra Pradesh	AKP 1 & 2	For sowing from May to August
	AKP 3, 4 & 5	For sowing from December to April
	H-1	For Anantapur, Kurnool, Cuddapah, Nellore and Guntur districts
Maha-rashtra	B-1 (early) E-31 (mid-late) A-16 (late)	For Konkan Division

Appendix 10. Chemical Composition of Ragi Grain (*Eleusine coracana* Gaertn.)

Proximate Principle	Proportion per 100g Edible Portion												
	India[1]	India[2]	Five brown[3]	One light brown[4]	Two white[5]	West Africa[6]	West Africa[7]	Africa[8]	Africa[9]	Mean[6]	Maize[1]	Wheat (whole)[1]	Rice (milled)[1]
Moisture-g	13.1	13.1	12.7	13.3	13.1	0.0	12.3	11.6	11.3	12.6	14.9	12.8	13.9
Protein-g	7.3	7.1	8.64	8.40	9.16	6.8	7.6	6.0	7.94	7.76	11.1	11.8	6.8
Fat-g	1.3	1.3	1.30	1.42	1.64	1.3	1.35	1.2	1.91	1.43	3.6	1.5	0.5
Carbohydrates-g	72.0	76.3	72.3	72.3	70.3	86.0	74.7	72.0	69.5	72.4	66.2	71.2	78.2
Fiber-g	3.6	—	3.1	2.8	3.2	3.3	1.7	6.8	7.64	3.6	2.7	1.2	0.2
Minerals-g	2.7	2.2	1.98	1.74	2.70	2.6	2.35	2.25	2.28	2.28	1.5	1.5	0.6
Calcium-mg	344	330	357	261	354	370	—	332	528	358	10	41	10
Phosphorus-mg	283	270	216	229	304	230	—	237	239	254	348	306	160
Iron-mg	17.4	5.4	5.5	5.1	6.0	4.8	—	—	—	7.4	2.0	4.9	3.1
Thiamine-mg	420	—	522	550	580	—	—	—	—	518	0.42	0.45	0.09
Calories	328	345	—	—	—	—	—	325	—	333	342	346	345

[1]Aykroyd, *et al.* (1963)
[2]Iyengar, *et al.* (1945–46)
[3-5]Kurien, *et al.* (1960)
[3]Mean of five brown seeded strains (RO 862, 870, 871, 883 and K-1)
[4]One light brown seed type—RCO 2
[5]Average of two white seed types (E.C. 4310 and Majjige ragi)
[6]Busson (1965)—Given on a dry weight basis (Moisture = 11.6%
[7]Porteres (1959)
[8]Gayte-Sorbier, *et al.* (1960)
[9]Fabriani (1939)

Appendix 11. Protein and Mineral Content of *Eleusine coracana* (Kurien *et al.*, 1960)

Component	Component as percent of whole grain	Crude Protein		Calcium		Phosphorus	
		Percent	Percent of protein in whole grain	mg/100g	Percent of *Ca* in whole grain	mg/100g	Percent of *P* in whole grain
Whole Grain	—	7.0	—	345	—	237	—
Husk	13.4	14.8	28	1,254	49	246	14
Endosperm (less Supernantant)	81.3	3.2	37	58	14	84	30
Dried Solids from Supernantant	5	45.5	37	2,234	36	2,438	58

Calcium/Phosphorus Ratio in Whole Grain = 1.46
C/P Ratio in Husk = 5.10
C/P Ratio in Endosperm = 0.91

Appendix 12. Amino Acid Composition of Different Genotypes of Ragi (*Eleusine coracana* Gaertn.) (Values expressed as percent of Protein

Amino Acid	Genotype or Variety												
	Co. 1[1]	Co. 12[1]	Bazaar[1]	Ceylon[1]	West Africa[2]	India[3]	India[4]	India[5]	Uganda[6] H.P.	Uganda[6] H.P.	Mean[6]	Wheat[5]	Rice[5]
Arginine	5.32	6.80	3.56	—	4.5	3.75	—	3.84	3.7	3.0	4.31	5.28	11.52
Histidone	1.50	1.40	2.50	—	2.2	0.90	1.45	0.96	2.2	1.9	1.56	1.44	3.04
Lysine	3.30	3.40	3.50	3.1	2.9	2.55	3.40	2.72	2.2	1.5	2.86	2.24	3.68
Tryptophan	1.65	1.46	1.56	1.1	1.2	1.30	1.55	1.28	—		1.39	1.12	0.96
Phenylalanine	5.20	4.90	3.00	2.7	5.2	3.00	4.3	2.88	5.0	4.7	4.09	5.28	5.12
Methionine	3.50	2.60	3.00	1.9	3.1	3.75	2.90	3.68	2.3*	1.9*	2.86	1.92	2.88
Threonine	3.10	4.30	3.03	2.9	4.2	3.4	—	2.08	4.0	3.6	3.06	2.56	4.00
Leucine	9.49	10.46	8.54	5.9	9.5	7.7	9.65	7.68	9.2	9.2	8.73	6.56	8.80
Iso-Leucine	6.17	6.70	6.41	3.1	4.4	4.25	6.50	4.32	4.1	4.2	5.02	3.52	6.08
Valine	6.86	7.43	5.77	6.3	6.6	6.50	6.75	6.56	6.2	6.2	6.52	4.00	6.72

[1]Kurien *et al.* (1960)
[2]Gayte-Sorbier *et al.* (1960)

[3]Kuppuswamy
[4]Balasubramanyam
[5]Aykroyd *et al.* (1963)
*Method of analysis gives slightly lower levels about—0.3%

[6]Stabursvik 1969

Uganda-MP: Medium-protein (9%) Brown-seeded Uganda strains Serere 199, Engenyi, Engorit (Mean)

Uganda-HP: High-protein, white-seeded strains IE-717 and 65 from India (Mean)

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The International Crops Research Institute for the Semi-Arid Tropics receives support from a variety of donors, governments, foundations, etc. including IBRD, IDRC, UNDP, USAID, etc.

The responsibility for all aspects of this publication rests with the International Crops Research Institute for the Semi-Arid Tropics.

PUBLISHED BY
INTERNATIONAL CROPS RESEARCH INSTITUTE
FOR THE SEMI-ARID TROPICS
1-11-256, Begumpet
Hyderabad-500016 (A P) India.