a pollinating line carrying the dominant fertility restorer gene. Cross pollination of the male sterile plant is affected by wind borne pollen from the restorer line. The hybrid seeds from the male sterile strips are harvested separately from the inbred seeds from the restorer strips (Figure 3.15).

There is a great deal of interest in the potential use of hybrid wheat. In the United States and Canada hybrid wheat production programmes are in progress and some of the private and federal seed companies or agencies are producing hybrid seed. In India, it will not be long before farmers sow hybrid wheat in their field.

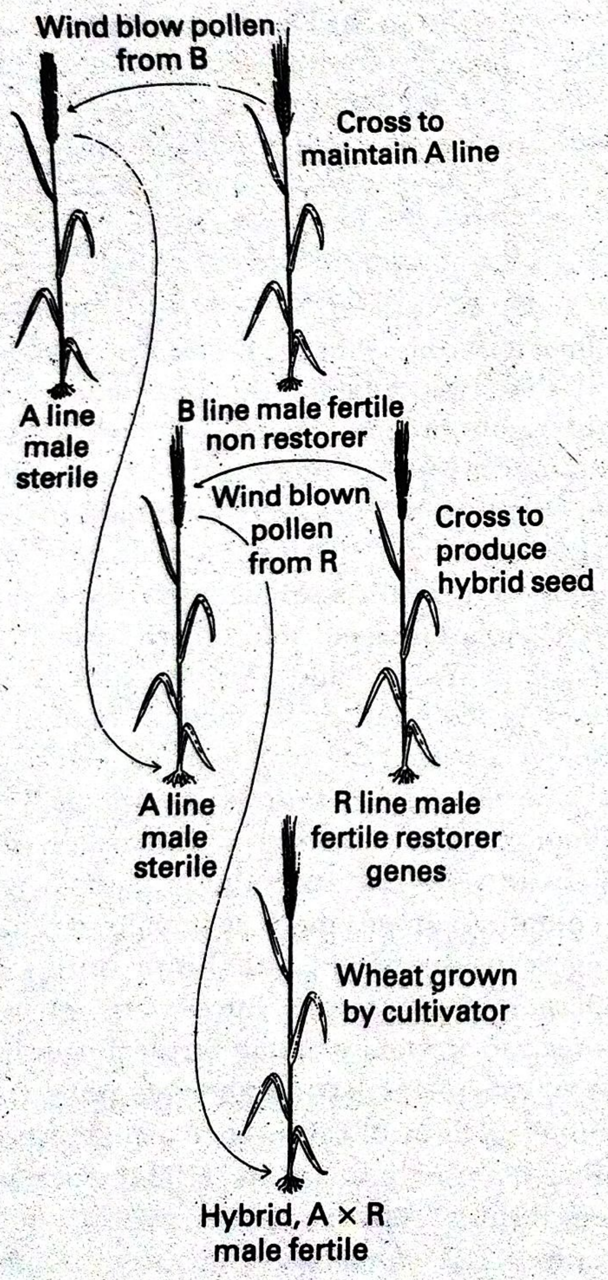

Figure 3.15 Scheme for producing hybrid wheat by utilising cytoplasmic male sterility and a fertility restoring gene.

***Oryza sativa* L. (n = 12)** **Rice**

Family: Poaceae

The genus *Oryza* belongs to the tribe Oryzeae of the subfamily Pooideae. The exact number of species belonging to the genus *Oryza* is not yet settled although a recent investigation of all type specimens available in different herbaria recognised 23 valid species. They are distributed in the tropical and subtropical regions of Africa, Asia, Australia and South America. The African continent, having the largest number of species, is usually considered to be the centre of origin of the genus *Oryza*. Most of them are diploid with somatic chromosome number 24, but some are tetraploid (2n = 48). Triploid hybrids are sterile. Haploid rice plants have been produced *in vitro* by Niizeke and Oono (1968) and Guha et al. (1970).

Of the two cultivated species, *O. sativa* L. is by far the most important and is now extensively cultivated throughout the warmer regions of the world, whereas the cultivation of the other species, *O. glaberrima* Steud. is confined to tropical West Africa.

Rice in the only cereal that is largely consumed whole by man as harvested (of course, after dehulling and polishing) and is usually simply boiled for direct consumption. Over one-half of the world's population subsists wholly or partially on rice. It is the principal food of the Far East where, in fact, meat, fish, fowl, vegetables, pulses and condiments are considered only as garnishes for the main dish of rice. In some countries of the Orient, the per capita rice consumption is estimated at 45–90 kg annually as compared to only about 3.6 kg in the United States.

HISTORY AND ORIGIN

Rice is known to have been grown in China nearly 5000 years ago. Remains of rice were found in the Yung Shao excavations in China, dating as far back as 2600 B.C. The sowing of rice was an important religious ceremony. It is stated that the emperor himself would plant the first and the best seed. From this and other ancient records it was long assumed that rice originated in China. However, this appears untenable as wild relatives are rarer in China.

There is a general consensus that rice was domesticated somewhere in India or Indochina, probably in southern India, where there are marshy expanses or areas with low intervening mountains and also periodic inundations, which are ideally suited to the cultivation of rice. The great varietal diversity of cultivated rice, the presence of the nearest known wild relatives, and many dominant genes in Indian rice varieties lend support to this view. Explorations in Jeypore tract, Orissa (India) have shown that the rice cultivated by the hill tribes at elevations between 500 and 1000 m, includes a large varietal diversity containing the whole range of variations from the wild perennial rice of *O. longistaminata* A. Chev. & Rochr. (sometimes called *O. perennis* Moench but this name is of uncertain application) through various stages of *spontanea* rice to cultivated *indica* and *japonica* (also *called sinica*) rices. There has been no large-scale introduction of rice biotypes into this area.

Carbonised rice has been recovered from an archaeological excavation at Lothal in Gujarat (India), dated to 2300 B.C. Lothal is considered to be a southward extension of the Harappa and Mohenjo-daro culture of the Indus Valley civilisation. Similar finds have been discovered from Rangpur (2000–1800 B.C.), Navdatoli (1550–1400 B.C.) and Hastinapur in Uttar Pradesh (1000–800 B.C.). There are also references to rice in ancient Hindu scripture dating back to 1300 B.C. The traditional use of rice in the religious ceremonies of the Hindus, associated with birth, marriage and death is a testimony to its great antiquity. Further information on the antiquity of rice in India is derived from the imprints of rice spikelets and kernels on potsherds (broken pieces of pots).

Rice spread eastward from India to china and thence to Japan, and westward into Iran, Iraq, Turkestan and Egypt. Rice is a symbol of fertility and as such was originally used in China to pelt newly wed couples in order to bring them good luck and assure them of many children.

It was introduced to Europe from India by Alexander the Great by 300 B.C. but it was not grown there until about A.D. 700. Rice was introduced into the American colonies in 1647 and was produced commercially in South Carolina about 1685. Rice cultivation in Australia began towards the end of the last century.

There are two divergent views regarding the origin of cultivated rices: polyphyletic, originating from several species and monophyletic, i.e. evolving from a single species. According to adherents of the polyphyletic theory *O. sativa* and *O. glaberrima* have evolved independently in their respective regions. *O. rufipogon* Griff. (*O. fatua* Koenig ex Trin.) of Asia has given rise to most varieties of *O. sativa* but some forms are derived from *O. minuta* J.S. Presl ex C.B. Presl (syn. *O. officinalis* Wall.) while *O. barthii* A. Chev. (until recently known as *O. breviligulata* A. Chev *et* Roehr.) of Africa is the progenitor of *O. glaberrima*.

Most modern taxonomists, however, consider the cultivated rices to be monophyletic, having originated from a common ancestral stock. The close similarity between *O. sativa* and *O. glaberrima* (the only differences are in glume pubescence, ligule size and colour of pericarp which is red in *O. glaberrima*) and the existence of intermediate forms between the two provide forcible reasons for this view. Sampath and Rao (1951), Sampath (1964) and Chandraratna (1964) proposed *O. longistaminata* (*O. perennis*) to be the progenitor of both the cultivated species. *O. rufipogon* of Asia and *O. barthii* of Africa are of collateral descent, developing as weeds along with the cultivated species as a result of natural crossing between *O. sativa* and *O. longistaminata*, and *O. glaberrima* and *O. longistaminata* respectively. In recent years this view has gained support from rice workers all over the world.

PRODUCTION

Rice is grown over an acreage of about 146 million hectares in the tropical and subtropical parts of the world. In 1994, the world produced an estimated total of nearly 534 million tonnes (Table 3.5).

Table 3.5 Area, production, and yield per hectare of rice (1993-94)

Continent	*Area (1000 ha)*	*Production (1000 t)*	*Yield (kg/ha)*
Africa	7 235	15 855	2 191
North and Central America	1 888	10 901	5 775
South America	6 242	18 106	2 901
Asia	130 027	485 077	3 731
Europe	378	2 113	5 591
Oceania	137	1 048	7 631
World Total	146 452	534 701	3 651

Source: *FAO production yearbook, 1994.* Volume 48.

Over 85 per cent of the world's rice production comes from China, India, Bangladesh, Japan, Pakistan and the adjoining islands in the Pacific. Small quantities of rice are also grown in few southern European countries like Italy and Spain. Only a little over one per cent of the world's rice production comes from the United States, yet it is a rice exporting country. China leads in the world production accounting for approximately 178 251 000 t. Although India ranks second in the world in rice production, it has to import rice sometimes to meet its requirements at home. Myanmar, Thailand, Laos, Vietnam and Cambodia are the major exporters in the world's rice trade.

India has the largest area under rice cultivation, with about 42.5 million hectares (about 29 per cent of the total world's acreage) yielding nearly 80 300 000 t in 1993–94 (FAO, 1994). It is grown to a varying extent in practically all states, but is most concentrated in the river valleys, deltas and low-lying coastal areas. The leading rice producing states are: West Bengal (12 110 000 t), Uttar Pradesh (10 210 000 t), Andhra Pradesh (9 560 000 t), Punjab (7 640 000 t), Tamil Nadu (6 750 000 t), Orissa (6 620 000 t), Bihar (6 110 000 t), Madhya Pradesh (5 960 000 t) and Assam (3 360 000 t).

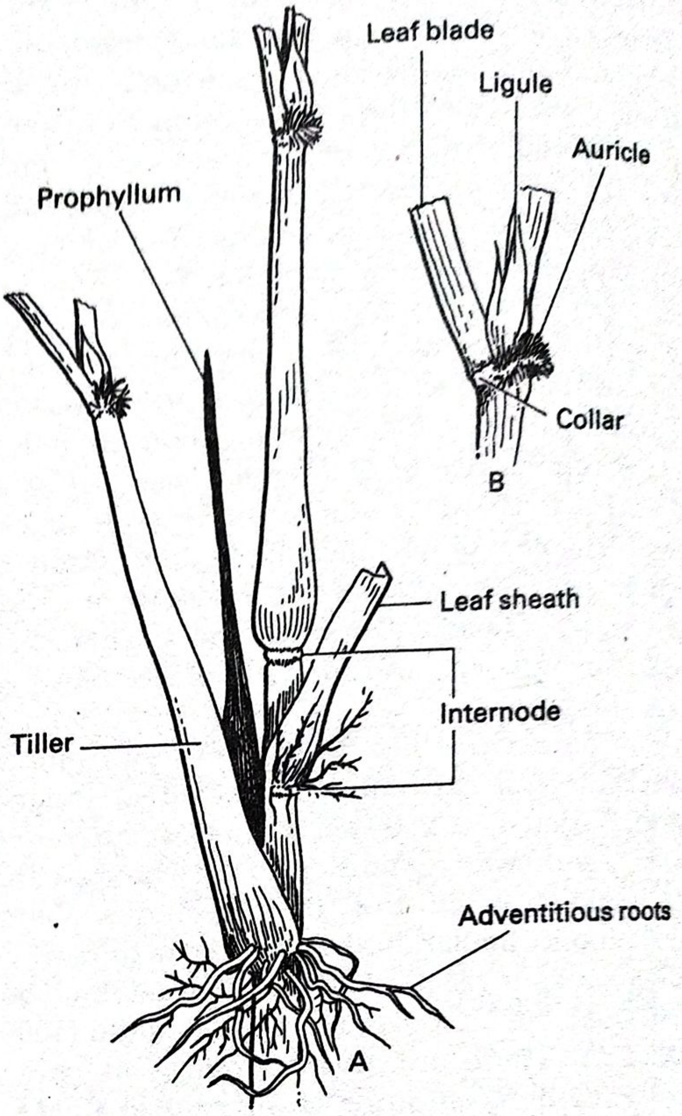

Figure 3.16 (A) Basal part of the main rice culm showing adventitious roots, prophyllum and two-ranked leaves, (B) a leaf joint showing the ligule and auricles.

MORPHOLOGY

The rice plant is a semi-aquatic, free tillering annual grass with a cylindrical jointed stem (culm), about 50–150 cm tall, but may go up to 5 m in floating rices. The internodes are shortest at the base, becoming progressively longer. Above each node, there is a pronounced thickening 'pulvinus' with an intercalary meristem. Generally speaking, rice has a shallow root system, its extent being controlled by the nature of the soil and the water supply. The first leaf at the base of the main culm and each tiller is rudimentary, consisting of a bladeless 'prophyllum' (Figure 3.16A). The leaves are borne alternately on the stem in two ranks– one at each node, each consisting of leaf sheath, leaf blade, ligule and auricles, the former encircling the whole or part of the internode. At the junction of the leaf sheath and leaf blade, there is a triangular membranous, usually colourless ligule that tends to split with age and is flanked on either side by a small sickle-like appendage, fringed with long hairs (auricles) Figure 3.16B). The leaf blade is long, narrow, 30–50 cm or more in length and 1–2 cm broad and somewhat pubescent having spiny hairs on the margins. The lamina of the uppermost leaf below the panicle ('flag' or 'boot') is wider and shorter than the others.

The rice inflorescence is a loose terminal panicle, 7.5–38.0 cm long (Figures 3.17 and 3.18A). The spikelets are usually borne singly, but clustered forms with two to seven spikelets together are known (Figure 3.18B). Each spikelet is laterally compressed and one-flowered, borne on a short pedicel and is subtended by two diminutive sterile glumes that are lanceolate, leathery, shiny structures ranging in colour from white, yellow to red or black. The flower is usually self-pollinated and is surrounded by lemma and palea that make up the hull or husk and remains attached to the grains in threshing (Figure 3.18C). The lemma is tough, papery and may be fully awned, partially awned or awnless, while the palea is

Figure 3.17 Close-up photograph of rice panicles.

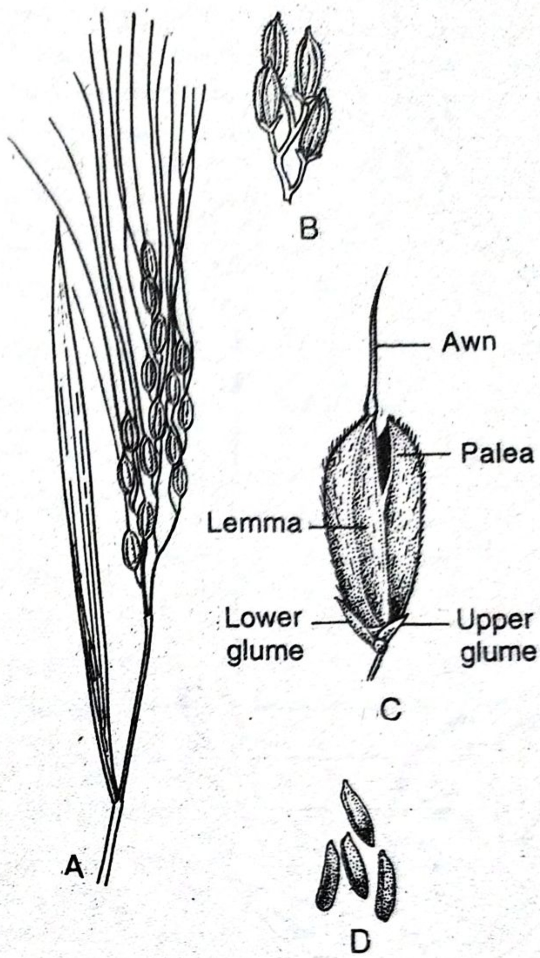

Figure 3.18 (A) Diagrammatic sketch of the rice inflorescence with 'flag' leaf or 'boot', (B) a portion of the panicle bearing single-flowered spikelets with small glumes at the base, (C) details of spikelet and (D) polished grains.

somewhat smaller, sometimes awned. Enclosed within the lemma and palea are two broad, thick, fleshy lodicules, six stamens in two alternating whorls, and a pistil with two plumose stigmas on two styles.

The mature rice grain is a caryopsis. Rice invested in the hull is called 'rough rice' or 'paddy', while that with the hull removed is known as 'brown', 'husked' or 'cleaned' rice (Figure 3.19). Rough rice consists of about 20 per cent hull. The grain coat is often pigmented and is differentiated into epicarp, mesocarp, cross cells, tube cells and spermoderm or integument. The remnants of the nucellar tissue are present just underneath the integument. The endosperm consists of a single aleurone layer of polygonal cells with a central mass of thin-walled parenchymatous tissue containing mostly starch.

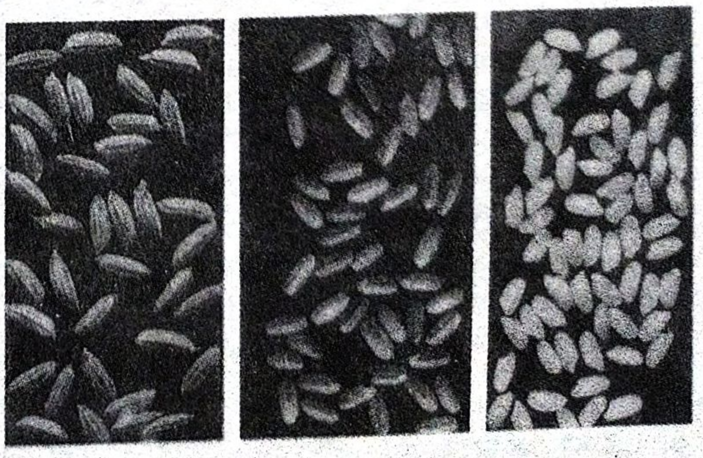

Figure 3.19 From left to right: paddy or rough rice; brown or husked rice; milled or polished rice.

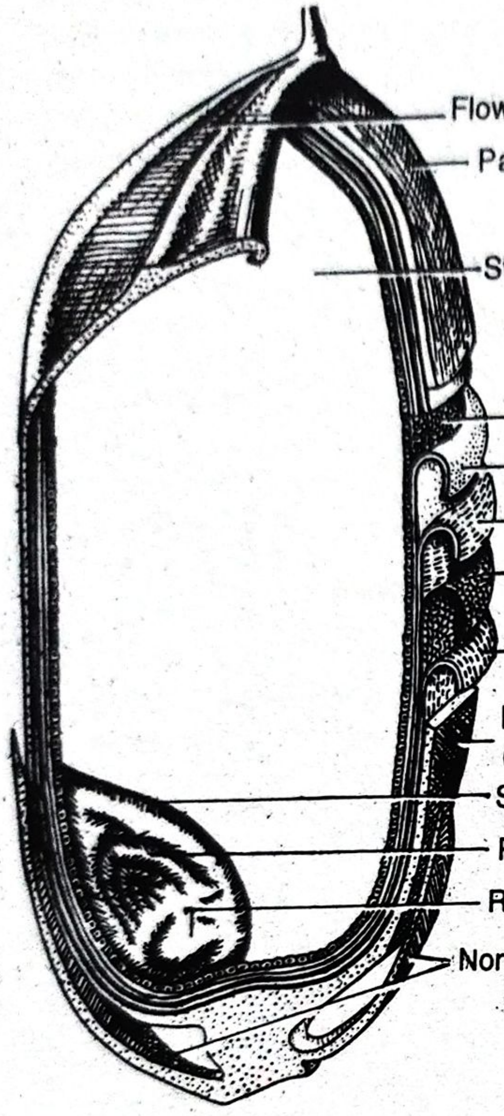

Figure 3.20 Diagrammatic longitudinal section through a rice spikelet.

The embryo is located near the base towards the lemma or ventral side of the grain and consists of strongly differentiated scutellum, plumule and radicle. The plumule is ensheathed by the coleoptile and the radicle by the coleorhiza (Figure 3.20).

The pericarp, nucellus, aleurone layer and the embryo (germ) collectively constitute the 'bran' which is quite rich in oils, proteins, mineral salts and vitamins; but most of the nutritional parts are lost during the milling operation.

GENETICS OF RICE

The 12 haploid chromosomes a, b, c, d, e, a´, b´, c´, d´, e´, a´´, and b´´ seem to have arisen from a cross involving two species with a haploid set of five chromosomes (a b c d e × a´ b´ c´ d´ e´). Through some meiotic irregularity two chromosomes (a´´ b´´) were duplicated in the hybrid and this, on chromosomal doubling, produced the fertile progeny *O. sativa*.

Many investigations on the mechanism of inheritance have been carried out with rice in India, Japan, the United States and other countries. These have been reviewed and summarised by several rice workers, prominent among whom are Kadam and Ramiah, 1943; Nagao, 1951; Ramiah and Rao, 1953; Nagai, 1959; Jodon, 1964; Takahashi, 1964; Chang, 1964; and Chandraratna, 1964. Until recently the genomic designation and system of gene nomenclature were quite varied. However, to avoid confusion, the International Symposium on rice genetics and cytogenetics sponsored in 1963 by the International Rice Research Institute, Los Baños, Philippines recommended a method of genome designation. A uniform system of gene symbolisation and gene registration was also recommended by the International Rice Commission of the Food and Agricultural Organisation of the United Nations. About fifty genes belonging to the 12 linkage groups have been identified.

CLASSIFICATION OF RICE VARIETIES

More than 8000 different rice varieties are known to exist in the world, of which over 4000 have been identified in India alone (Martin and Leonard, 1963). Varietal classification of rice has been based on a number of characters, of which only a few are being discussed here.

Agronomic classification

There are two general ecological types of rice; the lowland or irrigated and the upland or non-irrigated. The term upland and lowland do not refer to elevation, but to the use of irrigation water. Lowland rice is grown on lands that remain inundated with water from the time of transplanting until harvesting. It is either grown under a rainfed or an artificial system of irrigation and is by far the most important. Its yield is much higher than the upland rice. By contrast upland rice is entirely dependent upon seasonal rainfall and is, therefore, relatively unimportant.

There is yet another variety, 'floating' or 'deep' water rice which can withstand considerable depths of water. Floating rices are grown in the

CULTURAL PRACTICES

There are two principal systems of rice cultivation; dry paddy cultivation in which the crop is raised on dry ground very much like other cereals and wet paddy cultivation wherein the crop is grown under an assured and adequate supply of water and the plants remain in standing (but not stagnant) water from the time of transplanting until harvesting. The latter system accounts for nearly 90 per cent of rice cultivation in India and elsewhere. There is yet another system 'semi-wet paddy cultivation' where the rice is sown as a dry crop, to begin with, but the land is flooded by rain during the growing period.

Under the dry system, the land is ploughed immediately after the harvest of the previous crop and brought to a good state of tilth by repeated ploughing and laddering. Farmyard manure or compost is applied, well in advance of the sowing. Dry paddy cultivation is relatively unimportant at the present time. During 'wet' or 'puddle' cultivation, the land is irrigated about a month before sowing and thoroughly ploughed in standing water several times with a country or iron mouldboard plough and then levelled. Lumps of soils are broken down by working the land with bare feet or with ribbed rollers. In many countries, the flooded field is puddled with a rake-like implement pulled by animal or manpower (Figure 3.14). The aim of the puddling operation is to produce a soft soil with a fairly impervious texture.

Figure 3.14 Puddling a rice field prior to planting.

Fertiliser requirements

Before flooding and planting of rice seedlings, the fields are fertilised with farmyard manure or compost. Green manuring with leguminous crops is also widely recommended. Rice responds extremely well to nitrogenous (ammonium sulphate) and phosphate fertilisers (superphosphate or bone meal). The Addition of fertilisers just before panicle formation greatly increases the yield. The role of blue-green algae in replenishing the fertility of rice fields is now being greatly emphasised.

In the case of dry paddy cultivation, the seeds may be sown directly by broadcasting, drilling or dibbling, but in the wet paddy cultivation, generally the seeds are first sown in a small nursery and later the seedlings are transplanted into the flooded field. In the United States, the sprouted or pre-germinated seeds are sometimes dropped by aeroplane into the puddled and levelled field with very shallow water over the soil. In general, transplanting is superior as it gives a higher yield. The seedlings are raised either in a dry or a wet nursery; the latter is more frequently employed. The technique of seedbed or nursery preparation is similar to the one used for land preparation whether dry or wet paddy cultivation .

Transplanting

For transplanting, 18-30 cm long seedlings from the nursery are uprooted in small bundles. Every care is taken not to bruise the stem or break the roots. Transplanting is done on the same day or the next day in a well-puddled land with about 1.2-2.5 cm of water in the field. Three to four seedlings are pushed into the mud mound (hill) by hand, usually planted in regular lines 20-30 cm apart (Figure 3.15). The spacing between the two hills in each row is between 7 and 15 cm. In Japan, the transplantation operation is done almost with a religious fervour. The schools are closed at this time to allow the children to give a helping hand to their parents in the transplantation work.

Figure 3.15 Transplanting rice in India.

Weeding and interculturing

Crops sown under dry conditions need regular weeding and it adds much to the cost of cultivation. Weeding is usually accomplished by hand, but in the puddled fields it may be done simply by having the labourers wade through the field barefoot and trample the weeds down in the mud. The use of selective herbicides such as 2, 4-D, dinitro compounds have increased greatly in the recent years. They are applied at three stages of paddy cultivation; pre-planting, pre-emergence and post- emergence. The weeds that are common in the rice fields are barnyard grass, red rice, bull grass and Mexican weed; the former being the most troublesome.

In agriculturally advanced countries, weeding is usually done with the help of rotary weeders of the Japanese type. The process involves raking the soil all around the plants and seems to perform a two-fold function, that is, removal of the weeds and stimulating the crop by making available the soil nutrients. It also induces more tillering (Figure 3.16).

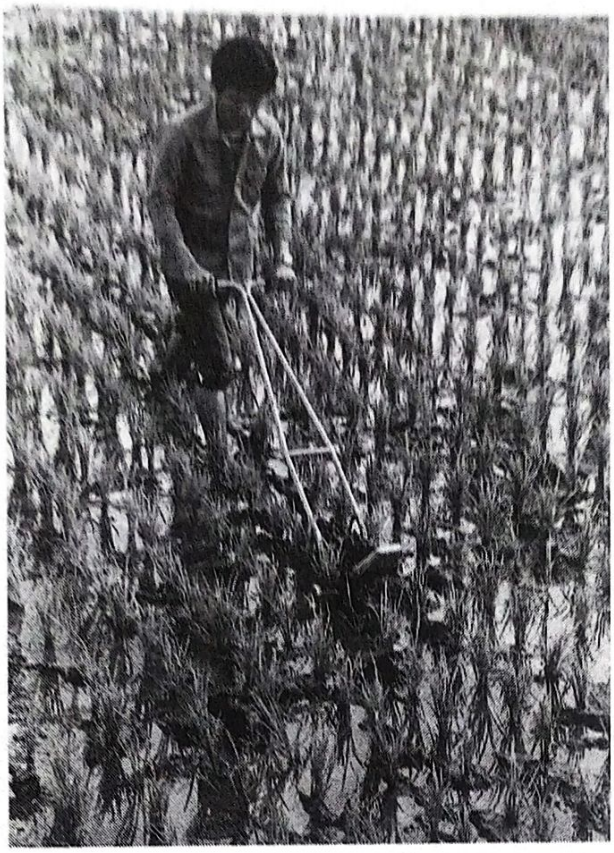

Figure 3.16 Interculturing of a rice field with a rotary weeder.

There are three distinct crops of rice grown in India; *aman* or winter rice, *aus* or autumn rice and *boro*, spring or summer rice. The bulk of the crop in India is the *aman* type which coincides with the south-west monsoon and is planted in June-July and harvested in September-December, with a maturation period of five to six months. The *aus* crop is of shorter duration (90-120 days), planted in May-June and harvested in September-October. The *boro* crop, on the other hand, is planted in December-January and harvested in March-April.

The cultural practices outlined in the case of lowland rice are referred to in the literature as the Japanese method of rice cultivation. Impressed with the trials on the Japanese method of rice cultivation at Kora Gramodyoga Kendra, Mumbai (9000-13 000 kg/ha of paddy against the average Indian yield of 840 kg/ha), a nationwide campaign was launched on 13 March 1953 by the Government of India to promote the Japanese method of cultivation (India's rice revolution, Ministry of Agriculture). This opened up a new era in pushing up rice production in India. The salient features of the Japanese method of cultivation are as follows:

- raised nurseries for growing rice seedlings
- a low seed rate in the seed beds
- very heavy manuring of the crop in the nursery as well as in the field
- transplanting paddy in rows in the field
- transplanting four to five seedlings per bunch (hill) and
- adequate interculturing and proper weeding.

HARVESTING

The right stage for harvesting paddy is when the panicles are turned down and are yellowish in colour, and the lower kernels are in the hard dough stage. Premature harvesting tends to lower the yield and also affects the milling quality. If the harvesting operation is delayed until the crop is completely ripe, there may be a loss from shattering. In most of the Asiatic countries, harvesting of the rice crop is usually done with hand sickles, whilst in the agriculturally advanced countries the crop is harvested by large self-propelled or tractor drawn combines that cut, thresh and bag the grains all in one operation.

PREPARATION OF RICE FOR CONSUMPTION

- ***Threshing:***

It is usually carried out within two or three days of cutting the crop and is accomplished either by beating the cut crop (sheaves) against a wooden log or trampling out the whole crop under the feet of a bullock or by pedal and power threshers. The grains are then winnowed free of dust, chaff, short pieces of straw and lighter grains by tossing it into the air above a sheet or mat.

Before milling, the paddy is dried in artificial driers so that the moisture content is reduced to 14-16 per cent.

- ***Milling process:***

The husk is removed either by hand pounding or by power driven machines (rice hullers). The former method is still being practised in many Asiatic countries and consists of pounding the rice using a pestle and mortar. Rice shelled by hand retains the bran and embryo largely intact, a matter of considerable importance as it contains vitamins, minerals and other essential nutritional materials. Hand pounding also gives a higher recovery of rice than the machine milling.

Modern machine milling removes the hull, bran, germ and part of the endosperm. For high-grade rice production, the paddy passes through the following operations in the mill; cleaning, hulling (also known as shelling), polishing and grading.

Rough rice is first fanned and screened to remove any extraneous matter such as small lumps of soil, stones, stalks, dirt, twine, nails, etc. The hulls are then separated from the kernels in a rice sheller which may consists of either two rubber rollers, revolving in opposite directions and at different speeds, or two hulling stones placed horizontally one above the other and only one of which revolves. As a result of abrasion, the husk is separated from the kernel. The sheller produces hulled grains, small paddy grains which have escaped hulling, husk and broken rice. The material then passes through a fanning machine where the detached hulls are removed. The remaining mixture is then conveyed to paddy machines (separators) where rough rice is separated from the hulled kernels. The small rice grains from the separators are returned to the hulling stones, now set close together, for the removal of their hulls.

The next step in the milling process is the removal of the outer brown layer or 'bran' and is accomplished in 'scouring machines' or 'hullers' (a misnomer because it removes the bran layer rather than the hulls). As a result of progressive scouring, the bran is removed and falls through the perforated screen to be carried away by suction. From the huller (or sometimes pearling cone used to affect further scouring), the rice passes to the bran reel to ensure further removal of bran. The bran is rich in oil, protein, mineral salts and vitamins. If it is not removed, it turns rancid and imparts an unpleasant odour and taste to the whole grain.

On the inner side of the outer brown layer is a finer, light coloured layer having the same composition as the outer and is known as the 'polish'. The rice kernels from hullers are then conveyed to a polishing machine called 'the brush' consisting of a vertical cylinder covered with overlapping pieces of pigskin or cowhide which revolves at high speed. Again, here more of the bran as well as some of the starch cells are rubbed off and screened out. The resulting light brown mass is known as rice polish.

To improve the sheen and maintain the quality of white rice, it is often slightly oiled and glazed with talc, glucose or some other material. The milled rice is then graded and bagged.

Paddy, on milling, gives approximately 20 per cent husk, 64 per cent milled rice (both broken and whole kernels), 13 per cent bran and 3 per cent of polish.

Parboiling

In certain Asian countries, especially India, Myanmar, Sri Lanka and Malaya, much of the rice receives a pre-milling treatment – 'parboiling', during which the paddy or unhusked rice is steeped in warm water for nearly 24 hours and then steamed under pressure until the outer layers of starchy endosperm are partly sterilised. Thereafter, the grains are dried and milled in the usual way. Parboiled or converted rice has many advantages over the ordinary milled rice: a). it undergoes less breakage during milling; b). it gives a higher yield of head rice (whole grains of milled rice); c). the kernels remain whole during long cooking; d). it possesses a better keeping quality, probably because of the partial sterilisation and e). more water soluble vitamins are preserved in the kernel owing to absorption of vitamin B in the bran and hulls by the underlying gelatinised endosperm.

Beri-beri, a disease caused by a diet lacking in thiamine, is very rare in countries where parboiled as well as hand shelled rice is a staple food.

UTILISATION OF RICE AND ITS BY-PRODUCTS

Rice is the most important of the world's cereals and forms the basis of the diet of millions of people in southeast Asia. About 90 per cent of rice is eaten in the form of various cooked preparations; the great bulk is plain boiled rice, often consumed with cooked pulses, curd, vegetables, fish or meat. The other Indian rice preparations are *kheer, firni* (made by boiling rice in milk, with the addition of sugar) and *pulao.* In South India, fermented preparations such as *dosa, idli* and *uppma* are prepared from a mixture of rice and black gram which is allowed to ferment for 8 to 12 hours and then toasted in a pan, or cooked in steam. Besides being consumed as cooked rice, it is also used as parched rice and parched paddy. Rice flour is used in confectionery, ice creams, puddings and pastry. Rice starch, apart from its food and laundering values, has wide industrial potential in the cosmetic industry, as a thickener in calico printing, in the finishing of textiles and for making dextrins, glucose and adhesives. Alcoholic drinks such as 'sake' in Japan and 'wang-tsin' in China are made from rice through fungal fermentation.

The rice husk is of little value as an animal feed because of its high silicon content. Hulls are used as a fuel, as bedding for poultry and for packing and insulation. Sometimes furfural is made from rice hulls. Ash from the burnt rice hulls is used as a filler in concrete and bricks, and as a source of sodium silicate in making soaps, polishes and other cleaning agents. The bran and rice polish, by-products of the rice milling industry, are valued as a stockfeed. Like groundnut oil, rice bran oil (RBO)* is used for edible purposes.

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* RBO contains good amount of disease-fighting natural antioxidants namely tocopherol and tocotrienol (Vitamin E complex), γ-oryzanol, phytosterols and squalene. These compounds have anti-mutagenic properties which curb cancer-causing free radicals. RBO in the diet may reduce LDL, cholesterol and triglycerides; inhibits platelets aggregation, thus may help prevent cardiac diseases.