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# India: Local and Introduced Crops [and Discussion]

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*Phil. Trans. R. Soc. Lond. B* 1976 **275**, 129-141
doi: 10.1098/rstb.1976.0076

*Phil. Trans. R. Soc. Lond.* B. **275**, 129–141 (1976) [ 129 ]
*Printed in Great Britain*

# India: local and introduced crops

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The oldest agriculture so far demonstrated archaeologically in India is that of the Harappan civilization, beginning in approximately 2500 B.C.; the Harappans had an advanced farming technology and a range of crops.

The earliest archaeological records are of species of west Asian origin, found in northwest India and Pakistan; locally domesticated species followed and cereal crops of African origin occurred remarkably early. Southeast Asian crops leave no archaeological evidence, but there are biological indications of substantial antiquity in India; crops of American origin are recent acquisitions.

Indian crops provide material for a study of the rate of genetic change under domestication. Native species, long domesticated and in contact with their wild relatives, are compared with domesticates introduced from outside, and separated from their parent species at different points in time. Seed propagated species are compared with vegetatively propagated crops and, among the latter, evolutionary change is demonstrated in spite of greatly restricted sexual reproduction.

## Introduction

The origins of agriculture in the Indian sub-continent are obscure. The earliest agricultural cultures so far excavated all yielded evidence of a well established farming system, with a range of crops and livestock. In one case relics of a husbandry system were found that were very similar to that still practised in northern India. Evidently, the earliest Indian agriculture so far revealed must have been preceded by a long period of farming development, but we have at present no archaeological evidence as to whether this took place in India or whether it began in some other country, and was then introduced into India.

Our knowledge begins with the period approximately 2400 to 1750 B.C., during which the Harappan civilization flourished in Sind, Punjab (Pakistan and Indian), Rajasthan and Saurashtra. East of the Harappan region in the Ganges valley, agricultural remains have been found that are dated to a period overlapping with, and following after, the Harappan period. Crop records in the Indian peninsula appear to be more recent than in northern India. The spread of dates so far recorded is from about 1600 B.C. to around the beginning of the Christian era. Moreover, the peninsula can be divided into a northern area (Madhya Pradesh and Maharashtra) and a southern area, with different crop distributions.

## The sources of India's crops

Crop plants are derived from wild species, many of which can still be identified. On the distribution of its wild relatives the provenance of a crop plant can be determined with some confidence. Indian crop plants are of very diverse origins. One group, of which rice is the most important, has its wild relatives in India, and the species of this group can be assumed to have been domesticated locally. A second group is related to wild species in West Asia, and is known from archaeological records to have been cultivated there before the earliest records so far established in India. This group, of which wheat and barley are the most important members, can be confidently regarded as introduced. A third group, including three common Indian cereals, sorghum, pearl millet and finger millet, have their relatives in Africa. In default of archaeological evidence from Africa, they must be regarded on the botanical evidence alone, as introduced in India. These three groups are well represented in the Indian archaeological record, and the information available (archaeological data from Vishnu-Mittre, ESWC 1974) is set out in table 1. It will be seen that the winter crops have not been found in the southern States of the peninsula, and the summer crops were rarely found at sites in the Indus province.

Table 1. Archaeological record of crop plants in the Indian subcontinent

| | crop | species | Indus province 2400–1750 B.C. | Saurashtra and west Rajasthan 2400–1750 B.C. | Gangetic province 2000–100 B.C. | Peninsula province 1600 B.C.–A.D. 100: M.P. and Maharashtra | Peninsula province 1600 B.C.–A.D. 100: southern states | cropping season | origin |
|---|---|---|---|---|---|---|---|---|---|
| cereals | wheat | *Triticum sphaerococcum* | C | — | R | R | — | winter | WA |
| | barley | *Hordeum vulgare* | C | — | R | O | — | winter | WA |
| | rice | *Oryza sativa* | — | C | C | C | C | summer | I |
| | kodon | *Paspalum scrobiculatum* | — | — | — | O | O | summer | I |
| | sorghum | *Sorghum bicolor* | — | O | — | C | — | summer | A |
| | pearl millet | *Pennisetum typhoideum* | — | O | — | — | — | summer | A |
| | finger millet | *Eleusine coracana* | — | — | — | — | O | summer | A |
| legumes | peas | *Pisum arvense* | R | — | O | R | — | winter | WA |
| | chick pea | *Cicer arietinum* | — | — | O | O | — | winter | WA |
| | lentils | *Lens culinaris* | — | — | O | O | — | winter | WA |
| | grass pea | *Lathyrus sativus* | — | — | O | O | — | winter | WA |
| | horse gram | *Dolichos biflorus* | — | — | — | O | O | summer | I |
| | gram | *Phaseolus* spp. | — | — | — | O | O | summer | I |
| oilseeds and fibres | linseed/flax | *Linum usitatissimum* | — | — | — | O | — | winter | WA |
| | mustard | *Brassica* sp. | O | — | — | — | — | winter | I |
| | castor | *Ricinus communis* | — | — | — | O | — | summer | I |
| | cotton | *Gossypium* sp. | C | — | — | O | O | perennial | I |
| | sesame | *Sesamum indicum* | O | — | — | — | — | summer | A |

Occurrence: C, common; R, regular; O, occasional. Origin: I, India; WA, West Asia; A, Africa.

Two other groups also contribute to Indian agriculture, crops of southeast Asian origin and crops of American origin. The important southeast Asian crops are sugarcane and bananas, and these leave no trace in the archaeological record. They were already in India at the date of the earliest written records, but how much earlier they were introduced is quite uncertain. Introductions of American crops have gone on since the discovery of America by Western Europe and the development of trade routes from Europe to India, both by the Mediterranean and round the Cape. One major uncertainty exists, and that is whether maize had reached India by a Pacific route before it was introduced by way of Europe. To these groups, which are made up of food and fibre crops, one can add such plantation crops as tea, which is indigenous, coffee from Ethiopia and rubber from Brazil.


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This is the extent of the diversity of Indian crop production. The subcontinent, with its range of climate from warm temperate winters to tropical summers, with monsoon rains varying in amount from practically nothing to almost the highest in the world, offers a range of circumstances to which almost all of the world's important crops have become adapted.

## The sources of India's livestock

In domestic livestock also, India exploits a wide range, but there has not been the same contribution from other continents. There is a remarkable contrast in domestication patterns between crops and stock. Each of the four continents, Europe, Asia, Africa and America has contributed to each of the three major categories of food crops, cereals, legumes and oilseeds. In the animal kingdom, on the other hand, domestication has been confined almost entirely to Europe (including Mediterranean Africa) and Asia. America has contributed no more than the turkey, the cameloids of the high Andes, and the guinea pig, and Africa (except for the Mediterranean coast) has offered nothing except the guinea fowl. Thus, Indian domestic animals are all of necessity either native domesticates or introductions from neighbouring regions of West Asia and Eastern Europe.

Allchin (1969) has summarized our knowledge of the archaeological evidence on domestic livestock. Briefly, remains have been found of all the animals now in use in India, but since wild relatives of these species existed in the past, and even still persist, in India, and there are no well defined criteria on which to distinguish wild from domestic stock, the evidence for domestication is inconclusive. That with most species domestication went on locally seems fairly clear. With cattle, evidence both skeletal and from pottery figurines indicates that they were of the humped zebu type. Only in Harappan rites, and in a Mesopotamiam context, are humpless cattle depicted. In peninsular India at Utnur during the last quarter of the third millenium B.C., in relics of a pastoral people keeping cattle, sheep and goats, anchylosis of the bones of the hock joint in cattle suggests that they were used as draft or pack animals. Thus it appears that in peninsular India, remains of pre-agricultural pastoralists have been discovered, dating as early as the earliest agriculturists so far identified in the sub-continent. This is as might be expected, and the dating sequence in the peninsula of pastoralists followed by farming communities offers no problems. In the north the earliest levels of the main Harappan sites lie below the water level in the alluvium of the Indus valley, and the information they contain of earlier crop production is consequently inaccessible.

## Cropping pattern and climate

Most of the world's food crops are annuals. Among the crops considered here, only two, bananas and sugarcane, are now grown as perennials, though cotton was a perennial until annual types were evolved in historic times, and there are perennials among the wild ancestors of a number of other crops. The growth and fruiting rhythm of an annual crop is governed by climatic factors, the most important of which are temperature, water supply and day length. Of these, in the Indian context, water supply is critical, but temperature and day length have both been incorporated in the control mechanisms that ensure that in its native area, each crop plant is adjusted seasonally to the expectation of adequate moisture or growth.

The effect of this physiological adjustment is seen most clearly in a comparison of the





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growing seasons of the crops of West Asia on the one hand, and those of India and Africa on the other. These are set out in table 1, and it will be observed that whereas the crops originating in India and Africa are crops of the summer monsoon season, those of West Asia are crops of the winter season. Northwest India is on the fringe of the Mediterranean/West Asian winter rainfall area, and the winter crops – wheat, barley, peas, chick peas, lentils, grass peas, Brassica oilseeds, and linseed – are all of West Asian origin, and in India are grown in the winter season in the north.

It is tempting to regard Harappan agriculture as a branch of the agriculture of West Asia, where records going back to the sixth and seventh millenium B.C. have been found, and where these winter season crops were domesticated. This is the more attractive since it is known that there were extensive contacts between the Harappan and Sumerian civilizations. Moreover, the dating is consistent with spread from the northwest. In general, the finds yielding the oldest dates have been in Pakistan and neighbouring areas of India. Finds in the Ganges valley and in central India were more recent (see Vishnu-Mittre, ESWC 1974). The slight but significant winter rains of the northwest appear to be important to these crops beyond what might be expected from their small amount. On the northern alluvium the greater part of their water requirement is met by irrigation. On the retentive black cracking clays of Madhya Pradesh and Maharashtra the winter crops rely on water stored in the soil from the summer monsoon.

The Indian and African species are summer crops and are found in sites excavated in peninsular India and as far north as the Gangetic province, but not in the northwest. In the archaeological record, the great area of overlap between the West Asian winter crops and the Indian summer crops is the Gangetic province, where wheat and barley and legumes have been found, and rice is almost universal. It is perhaps significant that in Saurashtra and western Rajasthan, wheat and barley were not recorded from Harappan sites, but rice was. From there, and southward in the peninsula wheat and barley and the winter legumes disappear, and rice, together with the African cereals and the Indian summer legumes, make up the crop list. The dates are later than the Harappan (1600–0 B.C.), and the impression gained is of a spread of agriculture from the northwest, facilitated by the acquisition of summer season crops by local domestication, on the one hand, and by introduction from Africa on the other. The archaeological data summarized in table 1 contain one inconsistency. The only record of *Sesamum* is from Harappa in Pakistan. *Sesamum* is a summer crop of African origin, and in its modern distribution conforms to expectation, in that it is a crop of peninsular India, and not of the northwest of the sub-continent. Further archaeological records of *Sesamum* are needed.

Sugarcane and bananas, the two perennial crops of southeast Asian origin, appear to have become established in northeast India, in an area of heavy and prolonged monsoon rains. There, local races of both crops arose from hybrids between southeast Asian domesticates and their wild Indian relatives (Hutchinson, ESWC 1974). Hence there have arisen groups of cultivars that as to one part of the genome are introduced, and as to the other part are indigenous to India, and these have spread widely in India and beyond.

The more recently introduced crops of American origin also fit into the climatic pattern in conformity with the climatic regime of the country of origin. Potatoes, of South American highland origin, were established first in Indian hill regions, and have only recently been adapted, genetically and by the development of husbandry practices, to growth in the plains. Groundnuts, from northern Argentina, have fitted into the agriculture of the summer season in Gujarat.

The history of maize in India is less certain. Sarkar, Mukherjee, Gupta & Jain (ESWC 1974) suggest on genetic grounds three separate introductions. Some primitive Himalayan strains appear to have been isolated from the main stream of maize evolution for a very long time, and the possibility of introduction before the discovery of America by Columbus cannot be ruled out. The more normal crop races of the Indian plains they divide into northern strains with a Mexican type variability pattern and peninsular strains with a Colombian type variability pattern. Both fit into the summer cropping pattern of this area. Vishnu-Mittre (ESWC 1974) concludes from the Indian names for maize that the post-Columbian introductions were by the Arabs, rather than the Portuguese.

## The technological competence of ancient India

The striking feature of this pattern is its sophistication over the whole period for which we have data. The crop record indicates extensive trade contacts, not only with the ancient civilizations of West Asia, but with civilizations at present unidentified in Africa. Sesame has been found in Harappan material, and African cereals were in peninsular India around 1800 B.C. Again, there is evidence of a high level of craftsmanship and of crop husbandry. Cotton was a common textile both in the Harappan civilisation and in peninsular India. Gulati & Turner's (1929) study of material from Mohenjo Daro showed that the textile craft was at that time technologically advanced. In crop husbandry, the uncoverng of a pre-Harappan field at Kalibangan in Rajasthan showed that a ploughing pattern still in use for mixed cropping in the winter season had been established as early as 2000 B.C.

Thus the picture is of an agricultural system of which as yet we do not know the beginning, but which we may reasonably suppose either arose in the northwest of the sub-continent or was introduced there from West Asia. It spread during the second millenium B.C. throughout the peninsula, and in the course of the spread was changed from a winter cropping, presumably irrigated agriculture to a summer cropping system. Doubtless irrigation was practised for rice, but a greatly enlarged rainfed cropping programme must have been developed, to which the African cereals made a major contribution.

## Genetic diversity

Only a selection of the more important Indian crops has been referred to. As will be seen, the diversity of species and of origin is very great indeed. Not only have species from four major areas outside India been added to the locally domesticated crops; long established species have been replaced by other species of the same genus. The Indian *Gossypium arboreum* has been much reduced by replacement with the American *G. hirsutum*, and the ancient *Triticum sphaerococcum* has virtually disappeared before another West Asian wheat, *T. aestivum*. Furthermore, during the period of agricultural activity in India, all these crops have changed and developed in response to farming circumstances, and during the twentieth century under the impact of deliberate hybridization and selection by plant breeders.

Anyone who has worked with any of the major crops of Indian agriculture must have been impressed with the enormous diversity that exists in them. The Indian agricultural literature of the first thirty years of the twentieth century is replete with accounts of 'unit species' selected out of the land races then in cultivation. In the middle 1930s the inadequacy of a taxonomic approach to this diversity was recognized, and a more statistical analysis was devised (Hutchinson, Panse, Apte & Pugh 1938). This change is an index of the growing appreciation of the nature and significance of genetic diversity in the interaction between a crop and its environment, and of the potential it offered for improvement.

Little attention has been paid, however, to the origins of this diversity, and the Indian situation offers some particular advantages for such a study. One must begin by questioning whether the whole of the diversity observed in a crop plant has arisen after domestication. There is good evidence for the view that major crop plants descended from widely distributed wild species, were domesticated repeatedly, and in widely separated areas. The four cultivated species of cotton, for example, certainly represent at least four separate domestications. Santhanam & Hutchinson (ESWC 1974) have gone further, and have noted the possibility that the major distinct races of *Gossypium arboreum* may have arisen in the wild and been separately domesticated. In rice also, it is clear that at least two domestications occurred, one in Asia and one in West Afrca. It may be suggested further, that rice was domesticated on more than one occasion in Asia, and that there may well have been pre-existing differentiation in the wild progenitor, of which the difference between the *indica* and *japonica* rices is an obvious example.

This level of differentiation is often not as readily useful to the plant breeder as that which has arisen within cultivated races. In this latter, comparisons can be made between indigenous crops, domesticated and selected while still in genetic contact with their wild progenitors, and introduced crops, genetically isolated from their wild relatives; between ancient introductions and recent acquisitions; and between seed propagated and vegetatively propagated species.

Compare first rice, still in genetic contact with its wild and weedy relatives: sorghum, separated from its relatives in Africa by transfer to India; and wheat, not only separated geographically from its wild and weedy relatives, but also genetically isolated by changes in ploidy. On Thoday's (1964) concept of disruptive selection, and on Doggett's (1970) analysis of disruptive selection in cultivated, weedy and wild sorghums in Africa, one might expect substantial differences between these three crops in the genetic diversity available to the plant breeder in India. Yet neither on the taxonomic descriptions of variability in the early years of the century, nor on the statistical analyses made more recently, is it possible to show that rice is more diverse than sorghum, or sorghum than wheat.

Turning to a comparison of ancient and recent introductions, differences do appear. Sarkar, Mukherjee, Gupta & Jain (ESWC 1974) report that the plains races of Indian maize (i.e. those that can confidently be ascribed to post-Columbian introductions) exhibit limited genetic diversity, and improvement of Indian maize varieties comes from bringing in a wider range of material from the American continent. In this respect, the genetic status of maize in India is markedly inferior to that of sorghum, which was introduced a millenium or more earlier.

Going a step further, and considering a vegetatively propagated recent introduction, Upadhya's (ESWC 1974) analysis of the history of the potato in India shows that the limited diversity in the established crop is the result of limited diversity in the original material, further reduced by selection to meet the constraints of Indian cropping conditions. In bananas, a vegetatively reproduced crop long established in India, diversity is the consequence of, first, hybridization between the edible *Musa acuminata* clones originally introduced and the wild indigenous *M. balbisiana*, and secondly, mutation in the resultant clones over the past 2000–3000 years.

The limited effect of this in comparison with the diversity generated by mutation and recombination in seed-propagated plants is indicated by Simmonds's (1959) estimate that for the world as a whole 'it looks as though there must be about 300 distinct bananas, 150 primary clones and, say, 150 easily recognisable mutants'. Compared with the diversity revealed by the study of sorghum in only two crop regions (Hutchinson *et al.* 1938), or with Shastry & Sharma's (ESWC 1974) estimate that the total number of rice cultivars in India may be 'roughly around thirty to forty thousand', this is a very small number indeed.

From these examples it seems clear that the extent of the diversity in a crop is not related to the presence or absence of wild or weedy relatives. It is affected by the breeding system and by the length of time the crop has been established in the country. Moreover, Simmonds (1962), in considering the situation in the bananas, concluded that there are far more mutants cultivated than could be accounted for on a basis of random survival. Bananas, because of the virtual absence of recombination, are very suitable for a study of the emergence of variability through mutation, and Simmonds' conclusion that their contribution to local diversity is a measure of the interest of the cultivator, and of the care with which he preserves them, may be accepted as valid over a much wider range of crops than the special case of the sterile bananas. As an example, sorghum may again be quoted, where Hutchinson *et al.* (1938) showed that different cultivators exercised preference for different grain colours in the stocks they grew for their own consumption.

## The pursuit of uniformity

There is a remarkable contrast between the diversity of peasant crops and the uniformity sought after in modern plant breeding and in commercial agriculture. As Simmonds (1962) puts it for the bananas, 'it seems to be the peasant cultivators who have been most active in preserving the mutants – as they often preserve variability in their other crops. By contrast, the great banana trades remain predominantly monoclone cultivations despite the occurrence of mutants.' The whole of agricultural thinking assumes the superiority of the pure strain over the variable land race. In livestock breeding the policy of breed societies and of animal breeding organizations has put a premium on uniformity. The advantages of uniformity in modern commercial farming are sufficiently obvious. Yet the disadvantages for future progress in farm productivity have long been recognized. In 1937 Hutchinson *et al.* (1938) wrote, 'the crop analysis data on both *jowar* and cotton, and general observations in other crops, show that the equilibrium condition between crop variability and combined human and natural selective forces is a balanced mixture, and not a pure type. In other words, the survival of the fittest is of the fittest population and not the fittest type, and the fittest population is a mixture of types.' In recent years there has been a move to counterbalance the erosion of diversity in the field by the maintenance of crop collections on experimental stations. The campaign to collect and preserve land races and primitive types of all crop plants has arisen from the fear that the spread of modern uniform strains will extinguish the variability on which successful response to new circumstances depends. The great increase in cross-breeding in livestock – now accepted and approved, even by breed societies – is a change stimulated by the same considerations. As so often happens in human affairs, however, bureaucracy and legislation are a generation behind modern thinking. Just as the dangers of narrowing the genetic base are becoming apparent, arrangements for the supervision and control of crop varieties are embalming in legislation an outworn faith in varietal uniformity. It is worth considering whether India, less hidebound in this respect than the West, might be imaginative enough deliberately to distribute new crop varieties that have within them substantial genetic variability.

## Change under domestication

Diversity is the raw material of genetic change, and we must now consider the kinds of change that have been fashioned out of it. Examples may be taken from cotton, rice and wheat. Cotton is of particular interest, in that *Gossypium* is a genus of long-lived perennial shrubs, and in all four cultivated species – two in the Old World and two in the New – annual types have been developed under domestication. Watt (1907) refers to Marco Polo, who visited Gujarat in A.D. 1290, Rashiddudin who was there in A.D. 1310, and the Rev. E. Terry who visited India in A.D. 1615, all of whom recorded that the cotton of the area was a long-lived perennial shrub. He goes on to refer to Dr Hove, who was there in A.D. 1787, and who 'repeatedly alludes to perennial cotton seen by him...but he also gives a full account of the cultivation of the annual plant, and devotes special attention to what he calls a new method recently introduced'. Thus it appears that the development of annual strains of the Indian cottons took place in about the 17th and 18th centuries. Both Old World species were involved, *G. arboreum* and *G. herbaceum*, and the morphology of the change was the same, and indeed was the same in the parallel evolution of the annual habit in the two New World species. *Gossypium* has a dimorphic branching habit. The main stem, and the laterals from the lower nodes, are vegetative. At some point on the main stem, fruiting branches arise at each node. In perennial cottons the first fruiting branch may not arise until the 20th node or later. In annuals the first fruiting branch arises at a very low node, usually below the 10th.

The change to a potentially annual plant is therefore basically simple, and given some genetic diversity for node number, can be visualized as arising readily in response to human selection. However, physiological characters that are not so readily recognized are also involved, and these must have been more difficult to alter by selection. A perennial cotton is genetically coded to flower at the right time in successive seasons. Two environmental stimuli can trigger the genetic mechanism, day length and moisture supply. In the most advanced annual cottons the genetic response to both these has been eliminated, and the plant grows, flowers and fruits in a sequence determined solely by sowing date. However, there still remain less advanced varieties, some of which are short day plants, with much delayed flowering in long summer days, and some are moisture determined, and do not set fruit until the beginnings of moisture stress as the monsoon declines. Thus, in a period of about 300 years, the morphological change necessary for the establishment of the annual habit has been achieved, and the complementary physiological changes have been brought about in most, but not in all cultivars.

In rice, also, the change from the perennial to the annual habits had accompanied domestication, but no morphological change was required comparable to that in cotton. Much more important has been the physiological diversification necessary to exploit the great range of climatic and agricultural circumstances under which rice is grown in India. According to Shastry & Sharma (ESWC 1974), 'this diversity has arisen primarily in response to three major cultural factors: the range of climate in the Indian sub-continent, differences in the duration and adequacy of the water supply, and variation in the intensity of the cropping system'. Rice was originally a summer monsoon crop (see table 1), and the summer monsoon crop varieties are rather long duration (more than 120 days), photosensitive and cropping and ripening as the days get shorter. Early varieties, maturing in 100–120 days have been developed which are neutral to day length, and are used to exploit the available water supply in seasons other than the main monsoon. Rice is a tropical and subtropical lowland, wetland plant, but a range of types has arisen that has greatly extended its adaptability. Cold tolerant cultivars are grown in the Himalayas, and drought tolerant strains under upland dryland conditions like other cereals. On the lowland wetlands the standard form is supplemented by deep water strains, adapted to conditions where the rice lands are flooded from 1 to 4 m deep during the growing season, and the greater part of the plant floats on the surface of the water.

Rice is unique, in that it normally grows in conditions wetter than would be tolerated by any other crop. The diversity that has arisen in the crop not only makes it possible to grow rice in the whole range of wetland conditions and seasons found in India, but also extends its adaptation to the dryland farming conditions to which the other cereal crops are suited.

Changes in the Indian wheat crop include changes at an early date in the species grown. The wheat of early archaeological remains in northwest India, and in Madhya Pradesh and Maharashtra, has been identified as *Triticum sphaerococcum*. It has survived in India in small areas until recently on account of its drought resistance, but long since ceased to be important. The greater part of India's wheat now is of the species *T. aestivum*. There is a substantial area of *T. durum*, particularly in Madhya Pradesh, and *T. dicoccum* persists as a relic in peninsular India.

*T. dicoccum* and *T. durum* are tetraploids, and *T. sphaerococcum* and *T. aestivum* are hexaploids. Their wild ancestors are West Asian and not Indian in distribution, and as with the other winter season crops (see table 1), they must all have been introduced. The times and rates of introduction of these species, and the reasons for substituting one for another, can now only be matters for speculation. The present distribution of the species is governed in part by climatic adaptation, and in part by disease incidence. The winter season adaptation of wheat has limited its spread into the peninsula, since wheat grain does not fill properly under the rising temperature of approaching summer. In the archaeological record the most southerly find is from Ter in Maharashtra. In recent times there have been repeated attempts to establish the crop in the south, and there is a small crop in the Nilgiri and Palni-Hills.

Rust attacks have driven the crop back, and even in the southern hills, rust is serious. Indeed it is serious for India as a whole, as the southern hills provide a refuge for the carryover of the disease from one season to the next. From there it spreads to the main wheat growing areas further north. Progress has been made in breeding resistant types for southern areas, and the crop is slowly being extended southward (Rao, ESWC 1974).

Wheat is subject to the attacks of a wide range of diseases in India, and the success of the crop has depended on the one hand on limiting cultivars to areas where the disease to which they are susceptible is not important (cf. *T. durum* to areas free of severe yellow rust attacks), and on the other on breeding, consciously or unconsciously for disease resistance. Modern wheat breeding in India is greatly preoccupied with disease resistance, but the success of selection – perhaps natural, perhaps human – for disease resistance in earlier times is illustrated by the emergence of leaf blight caused by *Alternaria triticina*. Rao (ESWC 1974) reported that the disease appeared on hybrids between Kenya wheats and local wheats of Maharashtra and Gujarat. He concluded that 'It appears that the disease must have long been present in India, so long indeed that the local strains have built up high resistance to it'.

These examples, from cotton, rice and wheat, illustrate the way in which Indian crop plants have diversified under the stimuli and the selective pressures of Indian agriculture. There has been progressive change along a single line, as with the evolution of the annual cottons, but diversification in response to the diversity of agricultural conditions has been much more important. In rice, the tremendous range of varieties that has emerged in response to the range of circumstances under which rice can be grown is a far more important evolutionary phenomenon than the change in habit from a perennial to an annual grass.

The overriding importance of diversification in crop plant evolution is relevant to a consideration of the present state and future prospects of crop improvement. The spectacular advances of recent years – the breeding of short strawed, fertility responsive varieties of cereals – have been advances in the direction of uniformity rather than diversity. It is significant that the outstanding success – the adoption of dwarf wheat – was a success virtually with a single variety. In contrast, success with new rice varieties has been much more limited, in large measure because of the much greater varietal diversity required in the rice crop. Indian wheat breeders are aware of the dangers of a one-variety success, and are breeding for diversity, but this survey of the history of Indian crops since archaeological times leads to the conclusion that diversity is not just one important feature of a crop plant; it is the major factor in its continuing agricultural success.

## Conclusion

In agricultural history, India has proved to be one of the world's most fertile areas. Is possesses a vast range of agricultual resources. Its soils are robust, and have withstood the onslaught of exploitive agriculture for more than four millennia. It has a great range of climate, and though the vagaries of the monsoons have been the cause of great variations in crop production, the source of India's famines has been the pressure of an essentially prosperous population on a rich resource base.

With these great natural advantages, Indian agriculture has adopted, and assimilated into farming practice, crops and stock both locally domesticated, and borrowed from all other agricultural systems of the world. The oldest Indian agriculture of which we have evidence was based on the crops and the farming pattern of west Asia. The rainfed farm lands of the Indian peninsula were exploited with crops introduced from Africa more than with those locally domesticated. And the discovery of the New World led to the introduction of American crops by way of Europe, and their integration in Indian farming. The result is one of the world's most diverse, and potentially most versatile, agricultural systems.

## References (Hutchinson)


Allchin, F. R. 1969 Early domestic animals in India and Pakistan. In *The domestication and exploitation of plants and animals* (ed. P. J. Ucko & G. W. Dimbleby), pp. 317–322. London: Gerald Duckworth & Co.

Doggett, H. 1970 *Sorghum*. London: Longmans.

Gulati, A. N. & Turner, A. J. 1929 A note on the early history of cotton. *J. Textile Inst.* **20**, T1.

ESWC 1974 References to essays by various authors in *Evolutionary studies in world crops* (ed. J. B. Hutchinson). Cambridge University Press.

Hutchinson, J. B., Panse, V. G., Apte, M. S. & Pugh, B. M. 1938 Studies in plant breeding techniques. III. Crop analysis and varietal improvement in Malvi jowar (*Andropogon sorghum*). *Ind. J. Agric. Sci.* **8**, 131–152.

Simmonds, N. W. 1959 *Bananas*. London: Longmans.

Simmonds, N. W. 1962 *The evolution of the bananas*. London: Longmans.

Thoday, J. M. 1964 Effects of selection for genetic diversity. *Genet. Today* **3**, 533.

Watt, G. 1907 *The wild and cultivated cotton plants of the world*. London: Longmans Green.




PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

*Discussion*

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Sir Joseph Hutchinson has given us a clear and thought-provoking statement of the evidence for local and introduced crops in India. I would like to comment on some points, mainly from the point of view of archaeology.

The Indian subcontinent, or South Asia as it is often now called, is placed geographically between West Asia and Southeast Asia, and it is therefore to be expected that it should have given and received loans of all kinds from both directions. That these should have included so many crops is therefore not unexpected: what is more surprising is that one whole group of crops, the millets, should have been of African origin, and introduced into peninsular India during the second millennium B.C. It is for archaeologists to investigate the medium through which the introduction took place. I may recall that there are already some slight indications of cultural influences which may be broadly called Egyptian, in the early part of the second millennium, in the shape of pottery head-rests in graves from Karnataka (Allchin 1966; Nagaraja Rao 1970), and that the maritime expedition of Queen Hatshepsut to Punt brought back plants and animals from that country, wherever it may have been. This certainly suggests that similar expeditions may have reached southern India, carrying crop plants among their trade goods.

We are faced in India with a curious paradox: in the relative lateness of the evidence available for the domestication of plants or animals, and the 'technological competence', as our speaker called it, of such evidence when it first appears. For this there may be several reasons, both the western and eastern borderlands, in Baluchistan and Bangladesh and Assam, are among the least known and least explored areas of the subcontinent, and we may confidently expect earlier evidence to be forthcoming from each when more work is done there. The technological competence suggests that there is earlier evidence awaiting discovery. Another reason may be that we are misled by the general tendency of cultural development in India: that groups at a relatively early cultural stage sometimes survived alongside, often in close symbiosis with, more advanced groups over very long periods. The hunting and collecting tribes who survived in several areas into this century may be cited, and from the archaeological record such Mesolithic settlements as Langhnaj or Bagor, where during the course of the occupation first domestic animals, then pottery, objects of copper and bronze, and even of iron, appear alongside a continuing stone technology.

Our speaker has drawn attention to the broad geographical division of cropping patterns, those of the north being dominated by winter crops and those of the south by summer. The persistence of this pattern into the present time is an example of another characteristic tendency in all parts of India for a culture trait to continue without change once it has become established. On sorghum I must enter a word of caution; in the one early occurrence so far reported from the northern province (from Ahar in southeast Rajasthan) Professor Sankalia has recently drawn our attention to the disturbed condition of that part of the site from which the specimens came, and suggested that until further proof is forthcoming these should be treated as belonging to the subsequent period, of the last centuries B.C. (Sankalia 1974). There is no such doubt concerning the other early occurrence, at Inamgaon, where the find belongs to *ca.* 1400–1200 B.C.

On sugar cane, although there is no archaeological evidence, the earliest literary references (from all the Vedic Samhitās except the Rigveda) allow us to conclude that the crop was cultivated fairly widely in Gangetic India by around 1000 B.C.

On technological competence I should like to refer to the Kalibangan field surface. I was more fortunate than Professor Steensberg, in that I happened to visit Kalibangan while the excavation was actually in progress. I made a particular examination of the stratigraphic position of the field; it is sealed by a layer of building make up which lies directly below the earliest Harappan brick walls in this part of the site. Therefore the field may be expected to have been ploughed around 2000 B.C. It lies only a few metres from the town walls and this leads me to wonder whether it was actually a common field or whether it may not have been part of a ritual ploughing connected with the laying out of the town, or of some sacrificial ground, as was later the case according to the Brāhmaṇas. Whatever was its purpose, there can be no doubt that it was of just the same pattern as that followed by the modern farmers of the region, and as such it is an extraordinary example of the longevity of Indian agricultural technology. The discovery of the field goes to the credit of Dr J. P. Joshi of the Excavations Branch of the Archaeological Survey and the team of excavators working with him. A good photograph of the field has been published (Thapar 1973).

Another instance of the same competence is suggested by a recent observation of Dr H. T. Lambrick (1973), that the Harappan expansion into Saurashtra and Gujarat may have resulted from an awareness of the much greater potential of those areas for growing cotton (and perhaps also wheat), compared with the Indus valley itself.

With regard to the sources of India's livestock, may I draw attention to the valuable work of Professor K. R. Alur, a retired veterinarian and co-author of a standard work on Indian cattle (Chelva Ayengar & Alur 1964). He has made a study of the cattle bones of many of the excavations of Neolithic-Chalcolithic sites from peninsular India and has shown repeated evidence of physiological change in the structure of the medullary cavities of modern cattle compared with those of 4000 years ago (Alur 1971, 1973). From this he has inferred that the Neolithic cattle were much closer to their wild ancestors than one might otherwise have supposed. This idea led us to re-examine the evidence from the Neolithic cattlepens, particularly from our own excavations at Utnur (Allchin 1966), and to formulate a new hypothesis regarding them, comparing them to the 'keddahs' in which wild elephants were trapped and penned for taming (Allchin & Allchin 1974). This hypothesis should be quite easy to test by further excavation, and I believe that there would also be great interest in applying the sort of quantitative approach proposed by Mr Jarman to the age and sex of the bones recovered. Incidentally the late Professor Zeuner, after his first visit to Gujarat, confidently asserted that the *Bos indicus* of the Indus seals was the same breed as that still flourishing in parts of western India and Pakistan. This breed stands in marked contrast to the much lighter beast shown on south Indian rock bruisings and paintings assignable to the Neolithic period, with which they must be more or less contemporary. This suggests the need for a wider survey of cattle bones to see, for example, whether the physiological change reported by Alur had already taken place in the cattle of the Indus region, and to study cattle bones from later periods and other parts of India.

In conclusion, may I remark that our speaker's discussion of 'genetic diversity' and the 'pursuit of uniformity' appears to touch on something very deeply rooted in Indian culture. In every walk of life the modern people of India display an almost perverse individualism, and it would come as no surprise to find a similar tendency at work in the past. As archaeologists we should certainly be prepared to discover evidence of whimsy and irrational choice in such matters as preference for seeds of one colour (or for that matter egg-shells)!

*References*

Allchin, F. R. 1961 *Utnur Excavations*. Andhra Pradesh Archaeological Series No. 5. Hyderabad: Government of Andhra Pradesh.
Allchin, F. R. 1966 Pottery head-rests from Narasipur Sangam. In *Studies in prehistory*, R. B. Foote Memorial Volume, pp. 58–63. (ed. D. Sen & A. Ghosh). Calcutta: K. L. Mukhopadhyaya.
Allchin, F. R. & Allchin, B. 1974 Some new thoughts on Indian cattle. In *South Asian Archaeology* 1973 (ed. J. E. van Lohuizen-de Leeuw, J. E. & J. M. M. Ubaghs). Leiden: E. J. Brill.
Alur, K. R. 1971 Animal remains. In *Protohistoric cultures of the Tungabhadra Valley* (ed. M. S. Nagaraja Rao), pp. 104–124. Dharwar: Nagaraja Rao.
Alur, K. R. 1973 Significance of faunal remains in archaeological studies. In *Radiocarbon and Indian archaeology* (ed. D. P. Agrawal & A. Ghosh), pp. 111–117. Bombay: Tata Institute of Fundamental Research.
Chelva Ayengar, H. N. & Alur, K. R. 1964 *Anatomy of the ox*. ICAR Monograph, 13. New Delhi: ICAR.
Lambrick, H. T. 1973 *Sind before the Muslim conquest*. History of Sind Series, vol. II. Hyderabad Sind: Sindhi Adabi Board.
Nagaraja Rao, M. S. 1970 Significance of pottery head-rests from neolithic sites. In *Studies in archaeology*: Professor H. D. Sankalia Felicitation Volume. *Indian Antiquary* (ed. G. V. Devasthali), 3rd series, **4**, 141–148.
Sankalia, H. D. 1974 *The prehistory and protohistory of India and Pakistan*. New Edition. Poona: Deccan College.
Thapar, B. K. 1973 New traits of the Indus civilization at Kalibangan: an appraisal. In *South Asian Archaeology*, Papers of the First International Conference of South Asian Archaeologists (ed. N. Hammond), pp. 85–104. London: Duckworth.

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The early history of agriculture in India will be clarified by the examination of materials from archaeological excavations in the Gangetic Valley. Supported by $^{14}C$ dates it has been discovered that the beginning of the Indian Neolithic preceded the pre-Harappan culture by some millennia.

The provisional dating of the Neolithic plant remains to 4000–3000 B.C. at Chirand dist. Saran, Bihar has been confirmed at the Neolithic site Koldihevah near Allahabad, U.P. where the lowest level of the Chalcolithic overlying the Neolithic has been dated by $^{14}C$ to $6480 \pm 185$ B.P., i.e. 4530 B.C. Obviously the Neolithic here is older than that. Potsherds bearing rice imprints have been found in all levels of the Neolithic, and rice remains seem to belong to the cultivated *Oryza sativa*. It would appear that the rice remains discovered at this site are the oldest recorded in the world.

It was brought to my knowledge that *sorghum* discovered from Ahar, the Chalcolithic site in Rajasthan, came from disturbed levels. Sorghum has subsequently been found at Inamgaon, a Chalcolithic site in Maharashtra where it is dated to 1500–1400 B.C.