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BIOTECHNOLOGY, GENETIC MODIFICATION, ORGANIC FARMING AND NUTRITION SECURITY

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Abstract

The world is witnessing several divides, of which the genetic and nutrition divides are some of the more serious ones. Blending Mendelian and molecular methods of breeding will help to raise the productivity of major crops. Such genetic enhancement coupled with the development of biological software for sustainable agriculture, such as biofertilizers, biopesticides and bioremediation agents, will help to foster an evergreen revolution movement, where productivity is improved in perpetuity without associated ecological or social harm. There are also opportunities for strengthening food-based approaches to bridging the nutrition divide through Mendelian and molecular breeding, as is clear from recent work in the development of quality protein maize, vitamin A-rich rice and protein-rich potato. Biotechnological tools will help farmers with small holdings to take to organic farming. Also, precision agriculture will be strengthened through precision breeding. By integrating pre-breeding in advanced laboratories with participatory breeding with farm families, the advantages of genetic efficiency and diversity can be combined.

Introduction

A Roman farmer Varro (1st Century BC) is reported to have stated "Agriculture is a science which teaches us what crops should be planted in each kind of soil, and what operations are to be carried out, in order that the land may produce **the highest yields in perpetuity**" (GT Scarascia Mugnozza, personal communication). Realizing this goal will call for continuous improvements in technology without associated ecological or social harm. In the Presidential Address to the Agricultural Sciences Section of the Indian Science Congress held at Varanasi in January 1968, I outlined the consequences of unsustainable agriculture (Swaminathan 1968, 1993).

"Exploitative agriculture offers great dangers if carried out with only an immediate profit or production motive. The emerging exploitative farming community in India should become aware of this. Intensive cultivation of land without conservation of soil fertility and soil structure would lead, ultimately, to the springing up of deserts. Irrigation without arrangements for drainage would result in soils getting alkaline or saline. Indiscriminate use of pesticides, fungicides and herbicides could cause adverse changes in biological balance as well as lead to an increase in the incidence of cancer and other diseases, through the toxic residues present in the grains or other edible parts. Unscientific tapping of underground water will lead to the rapid exhaustion of this wonderful capital resource left to us through ages of natural farming. The rapid replacement of numerous locally adapted varieties with one or two high-yielding strains in large contiguous areas would result in the spread of serious diseases capable of wiping out entire crops, as happened prior to the Irish potato famine of 1854 and the Bengal rice famine in 1942. Therefore the initiation of exploitative agriculture without a proper understanding of the various consequences of every one of the changes introduced into traditional agriculture, and without first building up a proper scientific and training base to sustain it, may only lead us, in the long run, into an era of agricultural disaster rather than one of agricultural prosperity."

The above anlaysis led to the intensification of research on the development of gene deployment strategies to match the physiologic races of pathogens, integrated pest and nutrient management systems, and other forms of environment-friendly technologies. Beginning with the discovery of the double helix structure of the DNA molecule by James Watson and Francis Crick in 1953, molecular genetics has taken rapid strides. Transgenic crop varieties now occupy 40 million hectares (James 2000). There is however considerable controversy on methods of assessing risks and benefits in relation to transgenic or genetically modified (GM) crops. It is becoming increasingly clear that scientific data alone cannot allay ecological, economic, health and ideological apprehensions. Hence there is need to adopt a "hasten slowly" attitude in relation to the spread of GM crops, particularly those intended for human consumption. Hasten we must in terms of scientific research, but slowly in terms of sale of GM foods, until all public apprehensions are cleared. The Cartagena Protocol on Biosafety represents the first step in developing internationally agreed guidelines for undertaking risk-benefit analyses in a manner which inspires public confidence.

Genetic Modification and Sustainable Agriculture

There are many potentially valuable applications of GM technologies in tropical agriculture, where biotic and abiotic pressures are high (Swaminathan 1982). The transition from Mendelian to molecular breeding represents a shift from generalized to precision breeding. Precision farming is an important component of sustainable agriculture. What role can precision breeding play in taking the eco-farming movement forward? The following are a few of the major scientific issues needing particular attention.

- Soil Health Care: Maintenance of soil health requires attention to the physical, chemical, microbiological and erodability characteristics of the soil.

- Water Quality: The quality of irrigation water, with particular reference to salt concentration is important in relation to crop growth.
- Plant Health Care: Steps will have to be taken to protect crops from the triple alliance of weeds, pests and pathogens. The pest pressure is particularly high in tropical and subtropical agriculture, because crops as well as alternate hosts are available in the field, particularly throughout the year.
- Genetic Homogeneity: Experience has shown that genetic homogeneity enhances genetic vulnerability to pests and diseases. Monoculture of transgenic crop varieties over large areas will enhance prospects for both the breakdown of resistance and the outbreak of pest epidemics.
- Abiotic Stresses: With intensive agriculture, problems of salinization and water-logging and pollution are increasing in intensity. Bioremediation techniques will hence become increasingly important. Droughts, floods, cyclones and other natural calamities pose additional threats to crop security. The consequences of potential changes in climate as a result of global warming are yet to be understood fully but it is clear that anticipatory research should be initiated to meet potential adverse changes in temperature, precipitation, sea level and ultraviolet-B radiation (Swaminathan 1998).
- Postharvest Management: Uniform ripening, attractive skin colour, processing and keeping quality, capacity to withstand transportation over long distances are all becoming important in the market, particularly in vegetables, fruits and flowers. Globalization of trade is opening up new markets for agricultural produce, but markets are also getting to be very choosy in terms of the quality of the produce. Thus we need both productivity and quality revolutions in crops. There is also need for value addition to primary crops, in order to increase income and nonfarm employment opportunities.

In the future, there will be increasing need for genetic material which can help to decrease or eliminate dependence on market-purchased chemicals on the one hand, and enhance adaptation to market preferences on the other. Research on bioremediation techniques will have to be stepped up to clean up problems arising from soil and water pollution. It is not surprising that the very first patent given to any living organism has been for a microorganism developed by genetic engineering by Dr Ananda Chakrabarty for cleaning up pollution caused by oil spills (Chakrabarty 1981).

Blending of Recombinant DNA Technology and Organic Farming Methods

Global interest in organic farming is growing (Fig. 1). This is because of the desire to increase biological productivity without ecological harm. The potential environmental, human health and social problems associated with genetic modification are leading to environmental groups wanting to discard recombinant DNA technologies in crop improvement. However, for every problem, there is a solution. Methods are being developed to find substitutes for antibiotic markers in recombinant DNA experiments. Also, techniques which would help to be as precise as possible in the transfer of alien DNA are being standardized. It is likely that most of the current biosafety and environmental concerns associated with GM crops will be satisfactorily addressed scientifically during the next few years, so that precision breeding becomes an important component of an economically and environmentally efficient ecofarming system. The following examples from the work and approach of the scientists of the MS Swaminathan Research Foundation (MSSRF) will help to illustrate the applied value of blending traditional practices with frontier technologies.

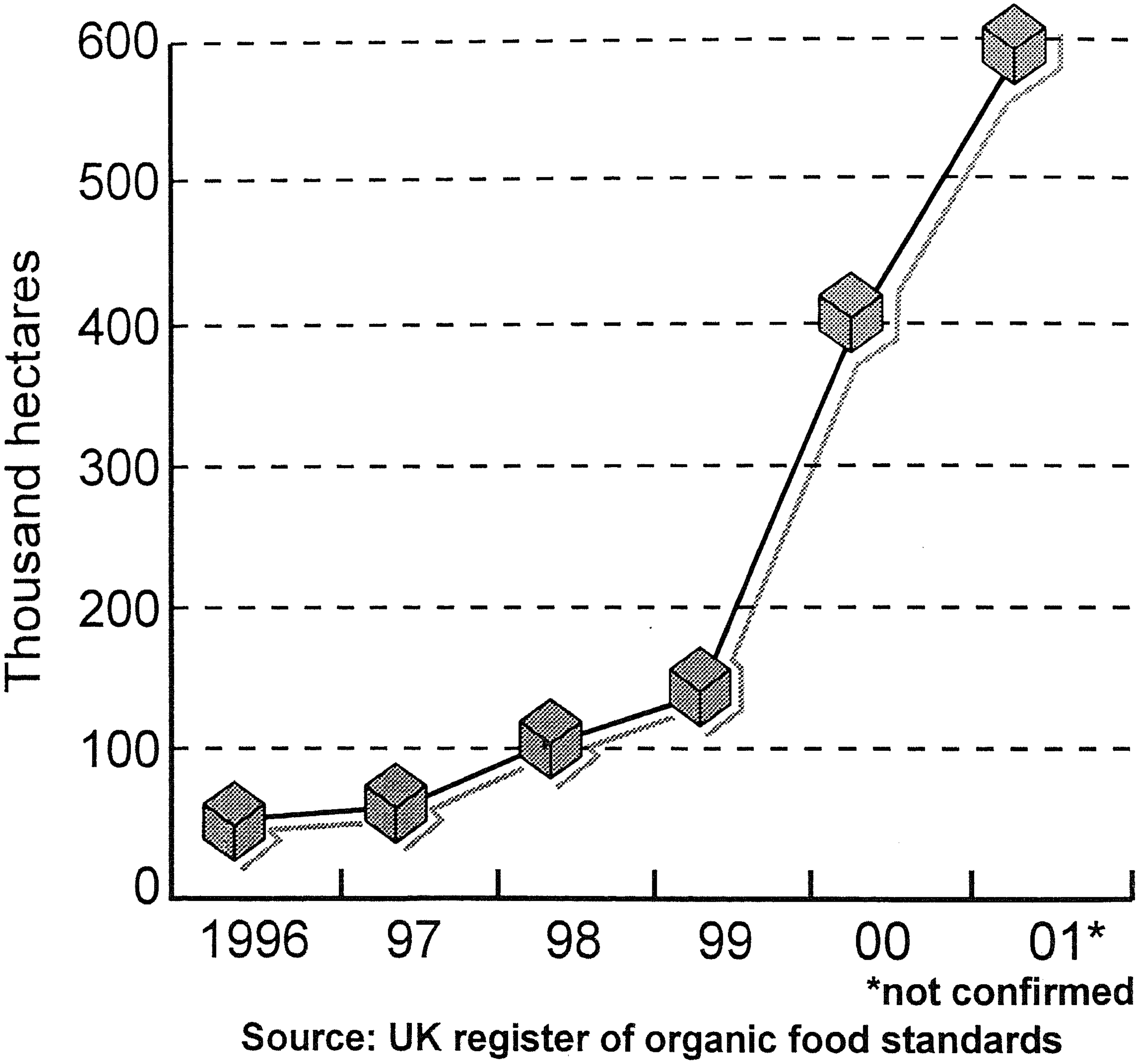

Fig. 1 — Growth in area under organic farming in the UK (*from Nature* **412** p. 666, 2001).

A. Pre-Breeding and Participatory Breeding

An integrated pre-breeding procedure leading to the production of novel genetic combinations and designer genotypes, and participatory breeding jointly with farming families for the development of location-specific varieties, would help to combine genetic efficiency and diversity in a mutually reinforcing manner. This will help to avoid the danger inherent in spreading single genotypes over large areas. Also, sustainable agriculture needs for its sustenance location-specific varieties (Fig. 2).

At MSSRF, a group of scientists headed by Dr Ajay Parida have been working during the past 8 years on the transfer of salinity tolerance genes from mangrove tree species to annual crops. This program was initiated with support from the Department of Biotechnology, Government of India, to prepare genetic material which will prove to be useful if sea levels rise, thereby safeguarding coastal agriculture.

One such gene, betaine aldehyde dehydrogenase (BADH) cloned from a highly salt tolerant mangrove species, *Avicennia marina* is currently being evaluated in transgenic tobacco and *Brassica* systems for its efficacy. BADH converts betaine aldehyde to glycine betaine. Glycine betaine is an effective compatible solute and its accumulation confers salinity tolerance in plants. The transgenic tobacco and *Brassica*, overexpressing the BADH from *Avicennia*, conferred salinity tolerance up to 250 mM NaCl. The work on isolation of a gene that can convert the ubiquitous choline into betaine aldehyde is being actively pursued. Other genes

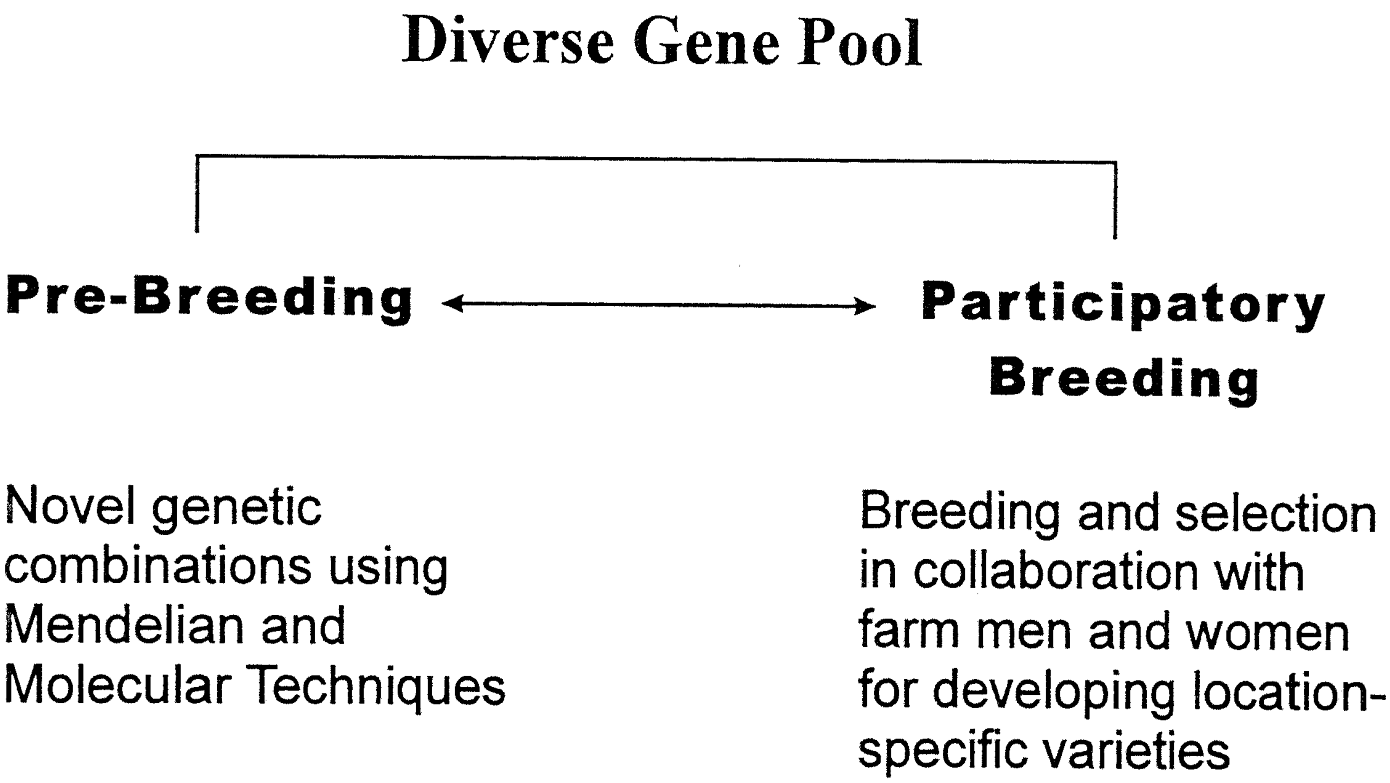

Fig. 2 — Integrating genetic efficiency with genetic diversity.

relating to stress resistance isolated and characterized from the mangrove species include catalase (CAT), superoxide dismutase (SOD), glyoxalase and sodium hydrogen antiporter. These genes are being evaluated for their expression in transgenic systems. Also, transformation work is in progress in rice and *Vigna* (Ajay Parida, unpublished).

Once transgenic plants with the desired salinity tolerance are developed, they will be used, after obtaining the necessary clearance from the regulatory authority, in breeding programs undertaken jointly with farm families. The aim will be to transfer to numerous locally adapted crop varieties the salinity tolerance character of mangrove species, in coastal as well as in inland areas where salinity is a problem.

B. Bioremediation: Sequestration of Salt

Salinity is responsible for major crop losses, particularly in semi-arid and irrigated agriculture. High salinity in soil may result from excessive irrigation or the excessive application of chemical fertilizer. Usually sulphates, chlorides and bicarbonates of Na^+, Mg^{2+}, and Ca^{2+} contribute to the salinity of soil. Sodium (Na^+) is the predominant soluble cation in most saline soil water, particularly in coastal areas. An alternate approach, for practising crop cultivation in saline environments, is the amelioration of soil salinity in agricultural habitats. Conventionally, it is done by addition of gypsum followed by leaching out of excess salts by flooding. A biological approach to solving this problem will be preferable. *Anabaena torulosa*, a blue green alga was found to grow and enrich the nitrogen status of moderately saline "Kharland" soils. *A. torulosa* was found not to accumulate Na^+ intracellularly but entrap the cation in its extracellular mucopolysaccharide sheath, thereby decreasing the availability of this deleterious cation to the crops. Research on the biological sequestration of salt from the soil may be rewarding (Apte & Thomas 1997).

Under a collaborative research program between the Bhabha Atomic Research Centre and MSSRF, a salt tolerant culture of *A. torulosa*, along with *AL31* were given for testing in the southern coastal region. Several field trials have been conducted so far. The trials have shown that *A. torulosa* established very well along with local *Anabaena* sp. in the field condition. Enhanced nitrogenase activity was observed in the field after transplantation. Up to 64% salt sequestration was observed when 1000 ml of innoculum was added (Sudha Nair, personal communication).

Biotechnological Applications in Organic Farming

MSSRF scientists are integrating a wide variety of biotechnological applications in improving the productivity, profitability, stability and sustainability of major cropping systems. Among the techniques of particular value are vermiculture, biopesticides, biofertilizers including stem-nodulating *Sesbania rostrata*, azolla, bluegreen algae and improved rhizobial strains. Such biopesticides and biofertilizers are best produced by village level self-help groups. In fact, there are good opportunities for gainful employment in the area of producing such biological software for sustainable agriculture (Fig. 3).

The era of precision breeding opened up by advances in genomics and genetic engineering has become an ally in the movement for environmentally sustainable advances in agriculture, a phenomenon christened "ever-green revolution" (*see* Swaminathan 2000). Knowledge is a continuum. The 20th century was marked by spectacular advances in crop productivity triggered by Mendelian breeding. The 21st century will witness even more spectacular progress from an intelligent integration of Mendelian and molecular breeding. The enormous power which transgenic technology has conferred on humankind imposes an ethical obligation, which should be discharged by developing transparent and multi-stakeholder method of risk-benefit analysis, capable of inspiring public confidence and trust. Technological push and ethical pull must go hand in hand.

At the same time, the tendency to decry all advances in the breeding of transgenic crops will not be in the interest of sustainable food and nutrition security. India's population exceeds a billion and there is no option in the future except to produce more crop per unit of land and per every drop of water. In my Coromandel Lecture titled "Agriculture on Spaceship Earth" (26 Feburary 1973), I mentioned "we are fortunately in a position to build a positive policy of economic ecology based on a series of Do's rather than Dont's (Swaminathan 2001).

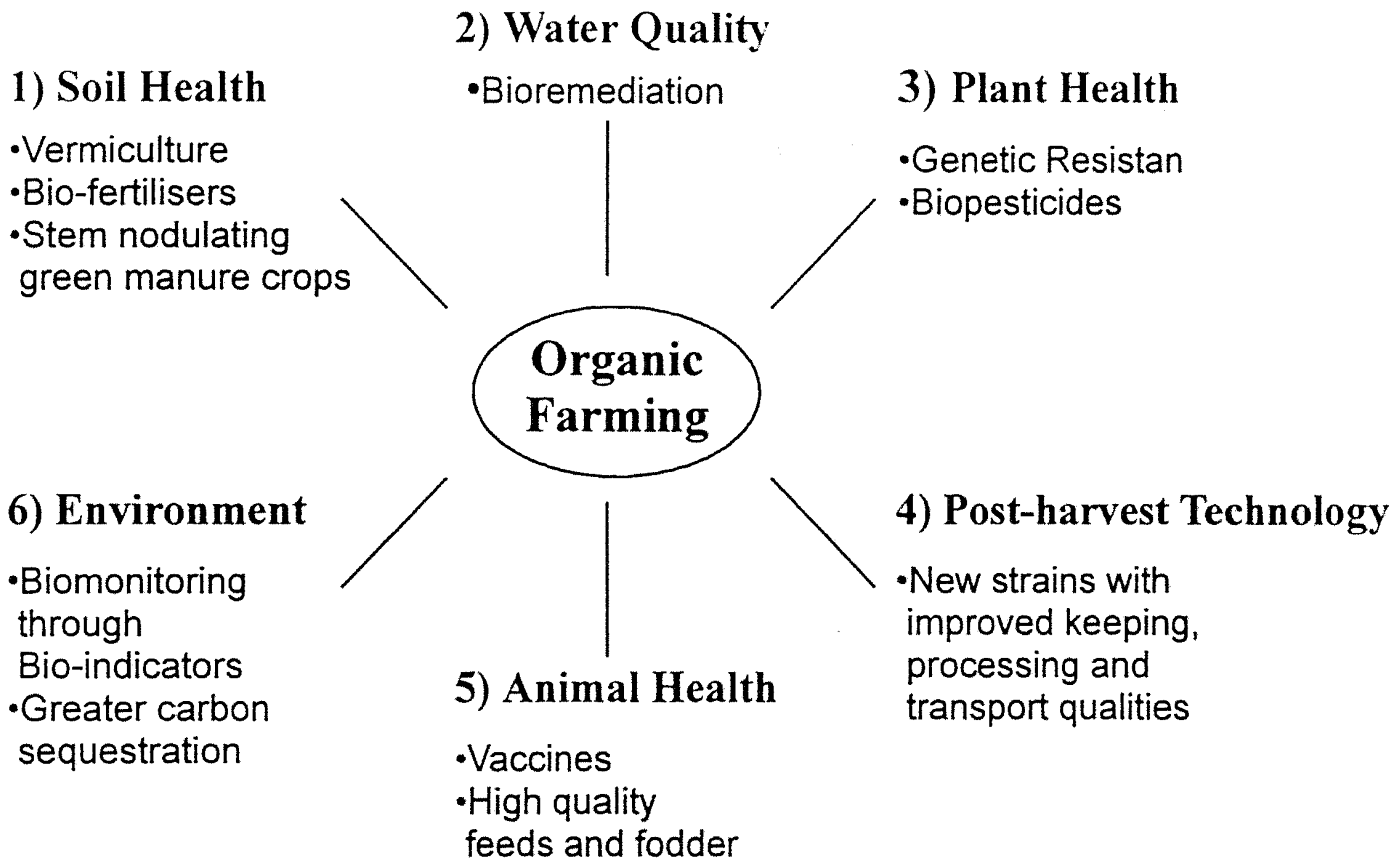

Fig. 3 — Biotechnological inputs for organic agriculture.

Biotechnology and Food Based Approach to Nutrition Security

1. FOOD-BASED APPROACH TO NUTRITION SECURITY

Such an approach will involve the following steps:

a. FOOD AVAILABILITY — This is a function of both home production and imports. In many developing nations, the gap between present and potential yields is high in most farming systems, even with the technologies currently available. High priority should hence go to bridging the productivity gap through mutually reinforcing blends of technologies, services and public policies. Also, mainstreaming the nutritional dimension in the design of cropping and farming systems is essential. There is no time to relax on the food production front. The present global surplus of food grains is the result of inadequate consumption on the part of the poor, and should not be mistaken as a sign of over-production. Developing nations should aim to achieve revolutions in five areas to sustain and expand the gains already achieved. They are briefly explained.

Productivity revolution: The scope is great because average yields are still low in most cropping and farming systems. However, the production techniques should be environmentally sustainable, so that high yields can be obtained in perpetuity.

Quality revolution: This can be achieved through greater attention to postharvest technologies and bioprocessing, as well as to sanitary and phytosanitary measures and **codex alimentarius** standards.

Income and employment revolution: This will call for an integrated attention to on-farm and non-farm livelihoods and to farming systems intensification, diversification and value addition. Postharvest processing offers scope for generating additional livelihoods through microenterprises supported by microcredit.

Small farm management revolution: Institutional structures which will confer upon farm families with small holdings the advantages of scale at both the production and postharvest phases of agriculture are urgently needed. For example, thanks to the cooperative method of organization of milk processing and marketing, India now occupies the first position in the world in milk production. Strategic partnerships with the private sector will help farmers' organizations to have access to assured and remunerative marketing opportunities.

In relation to factors of production, water is likely to become the key constraint during this century. Hence every effort should be made to enhance productivity and income per every drop of water.

Enlarging the food basket: During the last century, there has been a rapid decline in the number of crops contributing to global food security. In the past, local communities depended upon a wide range of crops for their food and health security. It is important that we revive the old dietary traditions. Particular attention needs to be paid to leafy vegetables which are rich in micronutrients.

b. FOOD ACCESS — Inadequate livelihood opportunities in rural areas result in household nutrition insecurity. India today has over 65 million tones of wheat and rice in government godowns; yet poverty-induced hunger affects over 200 million persons. Macroeconomic policies, at the national and global level, should be conducive to fostering job-led economic growth based on microenterprises supported by microcredit. Where poverty is pervasive, suitable measures to provide the needed entitlement to food should be introduced.

c. FOOD ABSORPTION — Lack of access to clean drinking water as well as poor environmental hygiene and health infrastructure lead to a poor assimilation of the food consumed. Nutrition security cannot be achieved without environment hygiene, primary health care and clean drinking water security. Culinary habits also need careful evaluation. Some methods of cooking may lead to the loss of vital nutrients.

d. TRANSIENT HUNGER — Ferro-Luzzi et al. (1994) have carried out a detailed study of seasonal cycling in body weights related to changes in weather. Any strategy for nutrition security should provide for steps to meet such transient hunger. The Indian State of Maharashtra introduced nearly 25 years ago an Employment Guarantee Scheme to assist the poor to earn their daily bread during seasons when opportunities for wage employment are low. Similarly there is need for mainstreaming considerations of gender, age and occupation in the national nutrition strategy.

2. FORTIFICATION AND SYNERGY AMONG DIETARY COMPONENTS

Our understanding of low cost and high synergy nutritional systems is growing. Fortification of flour with folic acid and genetic enrichment of staple grains with beta carotene and iron are now receiving attention.

Knowledge relating to the metabolic interrelationships among micronutrients is also growing, as for example among vitaminA-protein-zinc-iron-folic acid-vitamin C. However, in the absence of dietary interventions, iron-folate supplementation often fails to bring about a complete correction of anaemia. **Hence, the attack undernutrition-induced hunger and micronutrients deficiency-caused hidden hunger should be an integrated one.** Such an integrated strategy should provide for overcoming seasonal or transient undernutrition caused by loss of opportunities for livelihood during seasons of drought, floods or other natural calamities.

3. GENETIC ENRICHMENT OF NUTRITIONAL QUALITY

While the problems relating to the food and environmental safety aspects of genetically modified foods are yet to be fully resolved, there is little doubt that an integrated approach to Mendelian and molecular breeding is likely to make a food-based approach to nutrition even more effective in the future. The quantity and quality of proteins, carbohydrates, fats, vitamins and minerals can also be improved now. The scope for the genetic enhancement of nutritional quality will be evident from the following examples.

a. QUALITY PROTEIN MAIZE (QPM) — Scientists have long had an interest in improving maize protein quality. Quality protein maize (QPM) refers to enhanced levels of the two 'essential' amino acids, lysine and tryptophan, in the endosperm protein. Using Mendelian breeding methodologies supported by rapid chemical anlalysis of a large number of samples, scientists led by S Vasal and Evangelina Villegas at the International Maize and Wheat Research Centre (CIMMYT) in Mexico were able to slowly accumulate modifier genes to convert the original soft opaque-2-endosperm into vitreous hard endosperm type (Vasal et al. 1984). This conversion took nearly three decades. These remarkable new varieties look and taste like normal maize but the nutritive value of their protein is nearly equivalent to cow's milk. They also produce yields as much as 10% higher than the best local hybrid maize varieties and are more tolerant to biotic and abiotic stresses. QPM, which is a product of Mendelian breeding, promises improved nutritional value and cost saving for a wide array of products ranging from infant food to corn chips and feed for nonruminant livestock such as poultry. The impact of this breakthrough is likely to be felt throughout the food industry and has great promise in the developing world both for human and animal nutrition.

b. BETA CAROTENE-RICH RICE — A promising developing in the field of genetic engineering is the success in breeding a nutritionally enriched rice variety now popularly referred to as 'golden rice'. This genetically modified rice contains genes that produce high levels of beta carotene and related compounds, which are converted in the human body into vitamin A. Vitamin A deficiency (VAD) causes more than a million childhood deaths each year and is the single most important cause of blindness among children in developing countries. Rice plants do produce carotenoid compounds (that our body converts into Vit. A) but only in the green parts of the plant and not in the part of the grain normally eaten. Ingo Potrykus of the Swiss Federal Institute of Technology and Peter Beyer of Germany inserted genes from a daffodil (*Narcissus pseudonarcissus*) and a bacterium (*Erwinia uvedovora*) into rice plants to produce the modified grain, which has sufficient β-carotene to meet total Vit. A requirements in a typical Asian diet (Ye et al. 2000). If golden rice, currently still in the laboratory stage becomes a success in the field, it will help to strengthen the food-based approach to nutrition security, particularly among pregnant and nursing mothers.

c. IRON ENRICHMENT — Iron deficiency anaemia is the most widespread nutrient deficiency in the world, affecting an estimated 2 billion people worldwide. Between 40 and 50% of children under the age of 5 in the developing countries are iron deficient and iron deficiency accounts up to 20% of all maternal deaths. It also impairs immunity and reduces the physical and mental capacities of people of all ages. In short, iron deficiency is a major public health problem worldwide with enormous social and economic costs. Rice fortified with iron was created through the introduction of proteins from the kidney beans *Phaseolus vulgaris* by the same researchers of Swiss Federal Institute of Technology (Lucca et al. 2000). It is reported that the iron content increased 2-fold in the modified crop, currently under testing stage. Japanese scientists have also succeeded in enriching the rice grain with iron. The

International Rice Research Institute has developed rice breeding lines high in iron and zinc using traditional plant breeding techniques. This rice is currently being tested by Novitiates at a convent in the Philippines to know how well the nutrients are absorbed in the human body.

d. DESIGNER POTATO — Potato, which is the most important noncereal food crop, ranks fourth in terms of total global food production, besides being used as animal feed and as raw material for the manufacture of starch, alcohol and other food products. This crop has been genetically modified using a seed albumin gene *Ama*1 from *Amaranthus hypochondriacus* by researchers of the Jawaharlal Nehru University, New Delhi, India (Chakraborty et al. 2000). The *Ama1* protein is nonallergenic and is rich in all essential amino acids. Its composition corresponds well with the WHO standards for optimal human nutrition (Raina & Datta 1992). The JNU team was able to use a seed albumin gene with a well-balanced amino acid composition as a donor protein to developing transgenic potato. The genetic enrichment of protein quantity and quality in potato can make significant contribution to child and adult nutrition, as mashed potato can be fed to young children. Genetically enriched rice and potato can help to overcome concurrently the problems of protein-calorie malnutrition as well as micronutrient deficiencies.

The above are a few examples of the work in progress in improving through conventional and molecular breeding techniques protein quantity and quality in important food crops. Consumer confidence based on an appreciation of the scientific evidence and the regulatory checks and balances will ultimately decide whether or not genetically modified foods (GMFs) will make a significant contribution to feeding the 8 billion people who are likely to inhabit our planet by 2020. Marker-aided selection and transgenic approaches are two powerful tools to accelerate plant breeding to produce crop varieties with improved nutritional traits and qualities. An intelligent integration of Mendelian and molecular breeding techniques will help to enhance the nutritive value of staples. By integrating pre-breeding in laboratories with participatory breeding in farmer's fields, it will be possible to breed location-specific varieties and maintain genetic diversity in crop fields. Under conditions of small holdings organic agriculture based on farm-grown biological inputs, rather than market-purchased chemical inputs, will be greatly facilitated if the tools of biotechnology are harnessed as indicated in Figure 3.

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