6-6-3
PN-AAQ-807

Int. J. Environmental Studies
1978, Vol. 12 pp. 289–293

© Gordon and Breach Science Publishers Ltd., 1978
Printed in Great Britain

ISN=36131

AN ASSESSMENT OF THE ECOLOGICAL IMPLICATIONS OF NEW VARIETIES OF SEEDS

V. FERNANDO† and M. PUGH THOMAS‡

(Received March 16, 1978)

The history of the production and use of high yielding grain crops is outlined. The limitations of the nutritional value of both new and traditional varieties is given. The socio-economic benefits derived from the new crops is outlined. The environmental costs of the wide spread use of new high yielding varieties of crops in terms of genetic diversity, pest problems in mono-cultures and the need for greater human attention and increased energy input are discussed.

INTRODUCTION

It is estimated that man has used 3000 species of plants for food and has cultivated at least 150 species to the extent that they have been used for commerce. The tendency through the years has been to use fewer and fewer species, and to concentrate on the more economically efficient ones. As a result, five species of cereals now occupy a predominant position in world food production. These are: rice, wheat, corn, sorghum and barley. The indicative world plan for agriculture[1] clearly states that increases in cereal production must form a major part of any plan to increase world food production. Wheat and rice alone are the dietary mainstays of two-thirds of the world's population. Maize is similarly important in the tropical and sub-tropical parts of Central and South America, as is sorghum in parts of Africa and Asia. Although commonly thought of as calorie sources, they are also important sources of protein. Today, protein deficiency is considered as a major nutritional problem in many parts of the world, a fact which has particularly serious implications for the young. Nevertheless, many food efficient countries have a serious calorie problem as well. These two problems cannot, therefore, be dealt with separately; protein deficiency is impossible to correct if a serious calorie deficiency also exists.[2] Any increases in cereal production anticipated by the Indicative World Plan[3] has, therefore, to be productive both in terms of quantity and quality. High grain yields tend to be associated with depressed grain protein content in many crops and also, with undesirable shifts, in amino acid balance, especially in cereals. Thus, achieving both protein and calorie requirements at the same time is a difficult task.

The genetic manipulation of seeds to improve production in terms of both quality and quantity, and their use in agro-ecosystems is a widespread practise of contemporary agriculture. High yielding seeds, (The miracle seeds) when used with fertilizer, ample water and proper care, gives sudden and dramatic increases in yield.[4] This seed/fertilizer revolution or the "green revolution" has occurred most markedly in subsistence crops such as wheat, rice, maize and corn. With the discovery that the maize mutant opaque —2 had twice as much lysine as ordinary maize, the possibility of high quality seeds in terms of protein became a reality.[5] The discoveries of Ingverson and co-workers[6] and Axtell and co-workers[7] of high lysine mutants of barley and sorghum respectively, indicate the potential for genetic manipulation in producing high protein seeds.

BREEDING FOR HIGH YIELDS

The foundation for the "green revolution" was laid in Mexico when the co-operatively based Mexican Research Programme was initiated to increase the production of basic food crops. Wheat was one of the crops selected. By growing two breeding generations of all breeding material each

†The Ministry of Planning and Economic Affairs, Box 898, Colombo 1, (Sri Lanka).
‡Department of Biology, The University of Salford, Salford, M5 4WT (U.K.).

year at two different sites of differing altitudes, and by moving the planting lines back and forth, a new long-strawed variety of wheat was produced in a period of three and a half years. These long-strawed varieties never exceeded 4.5 tonnes/hectare in yield because of the effects of lodging.[8] This problem was solved in 1953 when several F_2 selections from the cross Norin 10 × Brevor to long-strawed varieties broke the 4.5 tonne yield barrier. Such crosses produced the famous dwarf and semi-dwarf wheats which were responsible for tremendous yield breakthroughs in Pakistan, India, Turkey, Afganistan and Tunisia.

In 1962 the average rice yield in South East Asia was about 1500 kg/hectare while Japan was producing about 5000 kg/hectare.[9] As a result of the work done at the International Rice Research Institute (I.R.R.I.) in the Phillipenes, a high yielding variety IR-8 was produced. One of its parents is a semi-dwarf variety from Taiwan and the other a tall variety from Indonesia. IR-8 is semi-dwarf and fertilizer responsive, enabling it to utilize fertilizer without lodging. It is highly tillered and has upright leaves which permits more heads per plant and more efficient light interception. The success of IR-8 has been due primarily to the isolation and use of two genetic systems. The semi-dwarf character is controlled by a single major recessive gene and modified slightly by minor genes. Photographed insensitivity is the other genetic system, and it contributes to the adaptability of the varieties. Sensitivity to photoperiod is apparently controlled by one or two dominant genes.[10]

During the early part of this century, it was observed that the ears of corn plants inbred for several generations became smaller and less productive. This change was attributed to a tendency of a pair of chromosomes to be homozygous as breeding proceeds. Hybrid seeds produced by transferring pollen from one inbred to another, however, grew into plants which gave greatly enhanced yields. In the operation of this technique, plant strains with non-functional pollen on their tassels are employed. These sterile strains are obtained when certain kinds of cytoplasm reacts with a specific chromosomal gene. This cytoplasmic male sterility insures cross pollination, in the production of hybrid seeds. Eighty percent of the U.S. corn crop carries this factor called the T-Cytoplasm. It was these strains which all possessed the genes associated with T-Cytoplasm, which proved highly susceptible to the leaf blight disease in 1970.

BREEDING FOR HIGH QUALITY PROTEIN

The first genes to be identified with a significant level of grain protein were the "Atlas 50" and "Atlas 66" varieties in wheat.[11] Subsequently, these strains were widely used to increase the protein content. Atlas genes can increase the grain protein content by as much as 2–3 percent. They appear to alter the nitrogen metabolism of the wheat plant.[12] It is now thought that the grain protein content could be raised beyond the level of Atlas 50 and Atlas 66.[13] Lysine is the nutritionally limiting amino acid in wheat. Common traditional wheats from the world wheat collection average 3.14 percent lysine, when lysine is expressed as a percentage of total protein. A lysine level of 4 percent would produce a reasonably good balance with other essential amino-acids if such a strain could be produced.

Rice protein is unique among cereals in that it is comprised mainly of glutemin.[14] The nutritional value of rice is attributed mainly to this property. High protein in rice usually results in low levels of some amino acids, particularly lysine. The rice collection at I.R.R.I. when screened for protein ranged from 5–17 percent among 7760 varieties. The mean was 10.6 percent.[15] In milled rice, however, protein content varies from 5–14 percent.[16] This is a major nutritional problem as rice is generally consumed in the milled state. The breeding goal pursued by I.R.R.I. is an increase in protein content of 2 percent over the variety IR-8, without a reduction in the high yields.[17] An induced mutant of rice with a higher than normal protein and lysine content was reported in 1968[18] and this line has been subsequently verified by the I.R.R.I.[19] Combination of this mutant with other high protein lines could lead to a significant additional increase in the protein content.

Maize protein is composed largely of zein, which is so low in the essential amino acids, lysine and tryptophan, that it will not support the healthy growth of young animals. The discovery in 1963 of the effect of the opaque – 2 gene on the amino acid composition of maize protein initiated research towards the possibility of genetic control of protein composition of cereals. The opaque – 2 gene raises the proportion of the glutemin protein fraction, that is rich in lysine and trytophan. Research in the United States and South America has established the nutritional superiority of high lysine—high tryptophan maize. At present, however, even in

these countries, the new
only a small area.[20]

SOCIO-ECONOMIC I

High yielding grains hav
traditional varieties—n
mature early, but unlik
are more responsive t
traditional varieties and
multiple cropping more
high significance in Asi
able land demands that
When adequate wate
Indonesian and Phillipi
two or even three crops
to imply that the "Gree
the only page in history
yield has been made b
agriculture.[21] Hybrid
phenomenon in the Ur
Also, the spread of ri
Taiwan and later to Ko
effect. A Sung emperor
introduced a rapid matu
which could be harvest
than the one hundred a
planting.[22] The unique
ary "Green Revolutio
time in which it has c
some observers[23,24] the
"Green Revolution" te
fundamental changes in
ing countries, and espec
these genetically mani
major hope and aspirat
for increased food pro
yield and quality, is un

ENVIRONMENTAL

(a) *General Considera*

The obvious socio-econ
seeds and their ability t
a short time has promp
developing regions of
This has often been
appraisal of its environ
ing the last decade the a
ences of using these
agriculture has been hi

2

these countries, the new varieties of maize occupy only a small area.[20]

SOCIO-ECONOMIC BENEFITS AND COSTS

High yielding grains have several advantages over traditional varieties—not only do they tend to mature early, but unlike traditional varieties they are more responsive to agrochemicals than the traditional varieties and their characteristics make multiple cropping more practical. The latter is of high significance in Asia, where a dearth of suitable land demands that production be intensified. When adequate water is available, Indian, Indonesian and Phillipine farmers can now grow two or even three crops each year. It is not correct to imply that the "Green Revolution" represents the only page in history where a quantum jump in yield has been made by applying technology to agriculture.[21] Hybrid corn produced a similar phenomenon in the United States in the 1930's. Also, the spread of rice culture from Japan to Taiwan and later to Korea had the same type of effect. A Sung emperor of the 11th century China introduced a rapid maturing rice from Indo-China which could be harvested in one hundred rather than the one hundred and seventy days after transplanting.[22] The unique feature of the contemporary "Green Revolution," however, is the short time in which it has caught hold. According to some observers[23,24] there is every indication that "Green Revolution" technology is bringing about fundamental changes in the agriculture of developing countries, and especially of Asia. The ability of these genetically manipulated crops to fulfil the major hope and aspiration of many governments, for increased food production, both in terms of yield and quality, is undoubted.

ENVIRONMENTAL COSTS

(a) *General Considerations*

The obvious socio-economic benefits of these new seeds and their ability to generate these benefits in a short time has prompted many countries in the developing regions of the world to adopt them. This has often been done without a proper appraisal of its environmental consequences. During the last decade the adverse ecological consequences of using these "miracle seeds" in crop agriculture has been highlighted.[25,26] The ecological significance of the use of selectively bred seeds in agriculture is four-fold.

1) The tendency for them to be planted in pure stands, thus reducing inter-specific variation in agro-ecosystems.

2) They survive only under cultivation so that the normal energy available to the agro-ecosystem has to be enhanced by outside energy sources.

3) Selective breeding has resulted in a loss of diversity of food plants often leading to the extinction of local plant races with valuable genetic resources.

4) Higher yields and quality proteins have been obtained by the deliberate narrowing of the genetic base of these species.

Cultivated plants have not always existed as genetically uniform populations growing in dense pure stands; they were once a genetically diverse population growing alongside and competing with many other species. Present-day crops, however, have been so altered by human selection that they survive only under cultivation. As a result their survival now needs human attention and care. Wilkes and Wilkes[27] have put this into perspective by saying that

> ... domestication has made these plants our captives, but human population has increased to such numbers that we could not possibly meet our food needs with wild plants, so we are ourselves held captive: that is dependant on the high yields of our cultivated plants.

Regarding the extinction of local plant races, the same authors write

> the extension of genetic technology and its limited base to the main centres of diversity of basic food plants, in the developing nations of the world, with the extinction of local races is analogous to taking stones from the foundation to repair the roof.

This problem is further compounded by the remarkably small number of basic food plants that feed mankind. Not only has the number of basic food plants decreased, but the inter-specific variety within each of these basic crops has also diminished. The seed production techniques that produce these high yield varieties leads to decreased genetic variability.

(b) *Consequences of Monocultures*

Monocultures of wheat, rice and corn are a consequence of modern agro-technology. Eliminating

3

genetically different types of seeds and replacing them over large areas with, for instance, similar disease resistant characteristics, though an accepted agricultural practise, is one with considerable risk. The sudden appearance of a pest to which a new crop is not resistant will not only destroy the entire crop locally but may also destroy the surrounding crops which too may be in the form of a monoculture. In such a situation, small changes in environmental factors may lead to a major pest outbreak. In this connection Streeter[28] observes

> . . . all across Southern Asia there has been a rush towards one dominant family of wheat prized for its yielding ability. All of these wheat carries the same kind of rust resistance, which means that if a new type of rust were suddenly to appear, much of the wheat crop of that vast stretch of land could be devastated almost overnight.

(c) *Loss of Genetic Diversity*

There is nothing biologically unsound about breeding for high yields; but it is shortsighted not to preserve and maintain the reserves of genetic diversity that still exists in native agriculture. Many of the reservoirs of genetic diversity, which in some instances have a continuous history dating back to the beginnings of civilization, are rapidly vanishing under the impact of the high yielding varieties which led to the green revolution. One factor of particular ecological significance of traditional varieties which are now threatened by the high yielding seeds, lies in their age and diversity. In this context Frankel[29] writes

> . . . in the regions of Asia and Latin America, where agriculture emerged and spread, crops have had a continuing evolution over many hundreds of years. They have acquired adaptations to environmental extremes, resistance to pests and diseases, ability to combat weeds, and above all a capacity to produce enough food and fibre to keep the cultivator alive and being populations, they had the ability to store a great range of variation for potential use in any contingency which was likely to occur.

Until the beginning of the deliberate selection and breeding for productivity and uniformity, these local strains of plants retained their characters of heterogenity and adaptation to local environments. It is alarming that the "green revolution" is occurring most vigorously in those regions which also contain the greatest range of genetic diversity. If the reservoirs of local populations are lost, future plant breeding will have to depend on the narrow genetic base of the new seed varieties. Although they can produce valuable genetic material in certain specific circumstances, they can in no way replace the broad spectrum of the natural genes in long-established crops. Therefore, if the native strains are given up in favour of new varieties, the genetic resource may become extinguished. Once this happens, the chances of recovering the tested, naturally evolved genes, would prove to be very difficult.

(d) *Narrowing of Genetic Variation*

Plant breeding depends on variation. What has changed in the transition from neolithic to scientific plant breeding is not only the nature of selection but also the nature and range of variation.[30] Variations generated by mutations and natural hybridisation and maintained by natural selection, escaped deliberate selection until crop agriculture came to be practised on a scientific basis. The transition of these primitive crops with a great range of variation to "new varieties" has narrowed their genetic base. This situation has been compounded by the minimising and removal of environmental differences over widely spread areas by the introduction of more uniform methods of agriculture. The ecological significance of this process is that while the genetic variability of the crops are becoming narrowed down, the diversity of common plant pathogens continue to remain unchecked as they are not subject to selective breeding. Genetic changes, either mutations or recombinations, consistently occur in individual pathogens, and if a pathogen suddenly grows successfully on a previously resistant host plant, it could spread across the entire plant population if the latter is genetically uniform.

(e) *Need for Human Attention*

All domesticated plants need human attention and care but the process of domestication has increased with the development of selectively crossed seeds. To obtain maximum productivity the energy normally available to the agricultural system has to be increased by the use of outside energy sources. On this subject Frankel[31] writes

> . . . they are for use in high producing agricultural systems, with intense cultivation, fertilizer application, plant protection, weed control, and when possible, irrigation.

It is this intensive agro-ecosystem as "a whole" that constitutes the green revolution rather than

the ole use of new high
tiful supply of water, fe
therefore, necessary if
benefits of this new se
slowing of the green rev
ing countries where the
ply, indicates the impo
success of the new vari
increase the availability
only be a heavy burde
countries, but will also
erable environmental
increased irrigation ma
logging; desalination,
the disruption of aquat

DISCUSSION

Considering the dem
increased populations,
ity cereals have a defin
takes into account the
benefits derived from t
imperative that their pr
encouraged, especially
of the world. The new
cally an attempt to stret
of the agricultural syste
duced. Therefore, th
deployment of other tec
izer, irrigation and pesti
energy from outside the
introduces an increased
cal energetics of the m
systems. These imbalan
cause irreversible and i
structure of agricultur
ecological implications
long time to manifest th
socio-economic benef
dramatically, in a short

In a haste to achieve t
the "miracle seeds" th
ignore these ecological
development based sole
of new seeds, ignoring t
may have long-term u
very productive system
nefits.

REFERENCES

1. Food and Agricultural
world plan for agricultur

sole use of new high yielding varieties. A plentiful supply of water, fertilizer and pesticides are, therefore, necessary if one is to obtain optimum benefits of this new seed technology. In fact, the slowing of the green revolution in certain developing countries where these inputs are in short supply, indicates the importance of their role in the success of the new varieties of seeds. Attempts to increase the availability of these factors will not only be a heavy burden to the economy of most countries, but will also be accompanied by considerable environmental disruption. For instance, increased irrigation may raise the risk of water logging; desalination, water-borne diseases and the disruption of aquatic ecosystems.

DISCUSSION

Considering the demands made for food by increased populations, high yielding and high quality cereals have a definite role to play. When one takes into account the immense socio-economic benefits derived from these "miracle seeds," it is imperative that their production and use should be encouraged, especially in the food deficient areas of the world. The new seeds, however, are basically an attempt to stretch the environmental limits of the agricultural system to which they are introduced. Therefore, they need the intensive deployment of other technical inputs such as fertilizer, irrigation and pesticides. This introduction of energy from outside the immediate growing areas introduces an increased imbalance to the ecological energetics of the more traditional agricultural systems. These imbalances, if unchecked, may well cause irreversible and irreparable damage to the structure of agricultural systems. Further, the ecological implications of these new seeds take a long time to manifest themselves. This is unlike the socio-economic benefits which show, often dramatically, in a short time.

In a haste to achieve the tremendous benefits of the "miracle seeds" there is often a tendency to ignore these ecological implications. Agricultural development based solely on the agronomic merits of new seeds, ignoring the ecological implications, may have long-term undesirable effects on the very productive system that generate these benefits.

REFERENCES

1. Food and Agricultural Organisation, Rome, *Indicative world plan for agriculture* (1969).
2. V. A. Jhonson and C. L. Lay, "Genetic improvement of plant protein" *J. Agr. Food Chem.* **22**, (4) 558–565 (1974).
3. Food and Agricultural Organisation, Rome, *Indicative world plan for agriculture* (1969).
4. W. C. Thiesenhusen "What changing technology implies for agrarian reform" *Land Economics* **50**, (1) 35–50 (1974).
5. E. T. Mertz, L. S. Bates and O. E. Nelson, *Science* **145**, 279–286 (1964).
6. A. J. Ingverson, H. D. Anderson and B. Koie, "Selection and properties of high lysine barley" *Proc. of research co-ordination meeting, Joint FAO/IAEA Div. of Atomic energy in food and agriculture IAEA/STI/Pub/230* (1972).
7. Axtell and co-workers (cf. ref. 6).
8. N. E. Borlaug, "Wheat breeding and its impact on world food supply" *Proceedings of the Third International Wheat Genetics Symposium* Canberra. (Ed. K. W. Finley and K. W. Shepherd) pp. 1–35 (1968).
9. D. H. Timothy, Plant germ plasm resources and utilisation. *Careless Technology: Ecology and International Development.* (Ed. M. T. Farvar and J. P. Milton) (Stacey, London, 1973) pp. 631–656.
10. T. Chang, "The genetic basis of wide adaptability and yielding ability of rice varieties in tropics" *International Rice Commission News Letter* **16**, 4–12 (1967).
11. G. K. Middleton, C. E. Bode and B. B. Bayless *Agron. J.* **46**, 500–512 (1954).
12. V. A. Jhonson and C. H. Lay (cf. ref. 2).
13. V. A. Jhonson and C. H. Lay (cf. ref. 2).
14. H. M. Beachell, B. O. Juliano and G. S. Khush, "Rice Breeding" 419–428, *International Rice Research Institute*, Philippines (1972).
15. H. M. Beachell, B. O. Juliano and G. S. Khush, (cf. ref. 14).
16. H. M. Beachell, B. O. Juliano and G. S. Khush, (cf. ref. 14).
17. V. A. Jhonson and C. L. Lay, (cf. ref. 2).
18. *International Rice Research Institute, Annual Report for 1971* Phillipines (1972).
19. *International Rice Research Institute, Annual Report for 1971* Phillipines (1972).
20. V. A. Jhonson and C. L. Lay (cf. ref. 2).
21. W. C. Thiesenhusen (cf. ref. 4).
22. M. Pereleman, "Second thoughts on the green revolution" *The Nation* 21–28 (July, 1971).
23. L. R. Brown, "Seeds of change", in *The Green Revolution and Development in the 1970s* (Praeger, New York and London, 1970).
24. N. Borlaug, I. Narvaez, O. Aresvik and R. G. Anderson, "A green revolution yields a golden harvest" *J. World Bus.* **4**, 10–19 (1969).
25. O. H. Frankel, "Genetic dangers in the green revolution" *World Agriculture* 9–13 (1970).
26. H. G. Wilkes, "Too little gene exchange" *Science* **171**, 955–963 (1972).
27. H. G. Wilkes and S. Wilkes, "The green revolution" *Environment* **14**, (8) 32–39 (1972).
28. D. C. Streeter, *The effects of public pressure on vegetation of Chalk Downland at Box Hill Surrey.* (Ed. E. Duffy and A. S. Watt) (. . . ., ..., 1971) pp. 459–468.
29. O. H. Frankel, (cf. ref. 26).
30. O. H. Frankel and E. Bennett, "Genetic resources in plants—their exploitation and conservation" *I.B.P. Handbook* No. 11, (1970).
31. O. H. Frankel, (cf. ref. 26).

5