PLANT BREEDING AND SEED SCIENCE
Volume 45 Supplement 2001

N. L. Darvey

The University of Sydney, Plant Breeding Institute, Cobbitty, NSW 2570, Australia

PLANT BREEDING AND BIOTECHNOLOGY – A PERSONAL VIEW

ABSTRACT

The impact of modern biotechnology on plant breeding is presented as well as consequences of the lack of social acceptance of these techniques in some societies. In this context the role of so–called conventional breeding methods is stressed, particularly the role of genetic resources in the future plant breeding is highlighted.

Key words: biotechnology, cytogenetic manipulation, food, germplasm conservation, GMO, manipulation

INTRODUCTION

This is the first time I have had the opportunity to speak at an Anniversary Conference, and I feel honoured that you have asked me to do so, first because I am an Australian, and Australia is a long way from the heart of Agriculture on the European sub–continent, even though our continent has a very strong agricultural base, and wheat has always been one of our main export crops. Second, I have always had a passion for understanding and being part of the movement for meeting human food needs, and as a triticale breeder, I am aware of the great potential this crop has for providing more food per unit area, especially in marginal environments. Third, this is my third visit to Poland, and I have been fortunate to see some of the problems of the past, and now have the opportunity to see a different Poland undergoing economic growth without political oppression. I have always admired the Polish commitment to agricultural research, and particularly their focus on germplasm conservation, which to me is of great importance, even in the modern era of plant biotechnology. And Poland is also the place where triticale has been a major crop, and there are scientists like myself, who are committed to its development as a cereal for human food. The work of Dr. T. Wolski and colleagues from Poznań Plant Breeders, and of IHAR in the breeding, pathology, and utilization of triticale will be the focus of an–

Communicated by Andrzej Anioł

other important meeting in 2002, when international scientists will gather here to look at the current status of this crop.

THE REALITIES OF GENETICALLY MODIFIED FOODS

You may well wonder why I chose to speak on the topic of plant biotechnology from a personal perspective, when in fact I am a plant breeder with only a peripheral interest in biotechnology. I guess there were two things that moved me to do so, firstly and most importantly to express the view that biotechnology needs to be viewed as a service to mankind, and not as a business; and secondly to express the view that any political will to deny biotechnological developments is an act of genocide against developing countries where the need for food far outweighs the potential risks associated with genetically modified foodstuffs. In a Rockefeller Foundation report (Reference No. 1559; 24 June, 1999), it is clear that the focus of the Foundation's grants is to assist the world's poor and excluded, and that the denial of the gains of Genetically Modified foodstuffs may prevent the development of disease and insect resistant rice, let alone rice with added b–carotene, which can provide a major source of vitamin A to 180 million children suffering this deficiency in developing countries, let alone the 2 million people who die from this deficiency each year. This is just one of several examples where genetic modification (GM) of plants can deliver better quality foodstuffs or tolerances to diseases, pests or environmental extremes (e.g. tolerance to acidity or flooding, etc.).

However the public backlash against GM foods has been brought on by the apparent commercial greed of private companies, who have rushed to get products on the market while disregarding human concerns i.e. the presence of antibiotic resistance genes in plants, the potential risks of cancer, the spread of herbicide resistance genes to harmful weeds, the fears of creating new strains of viruses from viral genes in plants, and the absence of independent testing of GM foods on humans. To some extent, Nobel Laureate, Norman Borlaug (2000), is right when he writes "Extremists in the environmental movement, largely from rich nations and/or the privileged strata of society in poor nations, seem to be doing everything they can to stop scientific progress in its tracks. It is sad that some scientists, many of whom should or do know better, have also jumped on the extremist environmental bandwagon in search of research funds. When scientists align themselves with antiscience political movements or lend their name to unscientific propositions, what are we to think?" Borlaug, himself recognises that "zero risk is unrealistic and probably unattainable. Scientific advances always involve some risk that unintended outcomes can occur. So far, the most prestigious national academies of sciences, and now even the Vatican, have come out in support of genetic engineering to improve the quality, quantity, and availability of food supplies".

On the one hand there is a need for private companies to be more open and sensitive to the possible dangers associated with GM foods in our society, and to carry out all the necessary safety tests, and where appropriate replace potentially harmful antibiotic genes with alternative safe marker genes eg. Novartis's new marker gene, *man A* (New Scientist) which enables the plant to digest a simple sugar and convert it to another form which is not toxic to the plant. On the other hand we as a society need to ask the kind of questions that Neale Walsch asks in his book 'Applications for Living', namely:

"So, we need to look at this race against time, and to consciously choose how we seek to evolve with regard to the technologies that have heretofore been driving the engine of our experience. To which technologies do we wish to say: "Just a cotton–picking minute. Just a moment. I don't think so." Can we say yes to this and no to that? Can we make wise choices and decisions? And can we apply the highest thoughts we hold in common about who we really are, as an overlay on the technological advances and applications that our society permits, allows, creates, encourages, and experiences?"

He asks the question 'Technology or the human spirit?' and reminds us that 'Technology won once before, and virtually obliterated human life on this planet – all but obliterated it' and 'have the ability to do that again'.

LOOKING AFTER OUR PLANET

There are a number of simple realities which we will need to confront at some time in the future; they have been stated and restated, and they are undeniable, but we as the people of the world refuse to take the warnings as seriously as we should for future generations. Perhaps the most important thing is that our environment through the actions of man is decaying. I can see as clear as daylight that we are not looking after our planet, and that the quality of our living is increasingly at stake. It is time that we paid attention to the slow, but sure, eradication of those things that define quality living, like the air we breathe, the changing climate patterns and the deliberate destruction of our remaining rainforests.

Not only is the quality of our environment in decline, but the land on which we grow our crops is also in decline. Desertification is on a massive scale of increase in the African continent, and even continents such as Australia have severe and escalating problems with salinity. It is generally recognised that with dwindling supplies of fresh water and climatic instability from global warming, the threat to our crops from drought, heat and cold is gradually becoming more serious. Thus our ability to meet human food needs is steadily declining, and plant breeders cannot keep up with either world population growth or land degradation. In a number of key rice–growing countries, yields have stagnated or fallen, especially in areas where 2–3 crops of rice are grown each year; this is despite the fact that the levels of soil fertility and richness of organic matter are higher than before. Only the most foolhardy would suggest that biotechnology will provide the answer, but at least it can and will assist in the area of crop protection (eg. disease or weed control) and resource utilisation (eg. photosynthetic efficiency, food quality, etc.).

PLANT BREEDING AND BIOTECHNOLOGY AS SERVICES TO MANKIND

I teach a course in plant breeding at my university, and one of the first things we look at is the definition of the term 'plant breeding'. Interestingly most of these definitions focus on the science or art of plant breeding, and define it as a continuation of the evolutionary process under the control or will of man, and sometimes of greater use to mankind, but few if any definitions of 'plant breeding' define it as a service to mankind, and so my role today is to come up with such a definition which holds in balance the commercial interests and the needs of society. The end of the 20th Century and the beginning of the 21st Century have been marked by the 'user pays' principle, and the gap between the haves and the have–nots is steadily increasing. Government is continually relinquishing its responsibility in the areas of education and health care, and while a basic level is provided, technology is moving at such a great rate and has become so expensive, that Governments have become less and less able to bring about social equality, and more and more research and development is moving into private hands as companies compete to be the first with new technologies, and thus the most profitable.

In the area of plant breeding in Australia, there is an ongoing and significant shift from public to private plant breeding, and concurrent with this has been a decrease in communication and cooperation. Part of the reason for this is that much of the future is seen in the area of biotechnology, and biotechnology is very expensive and somewhat beyond the public purse in its affordability. Thus plant breeding is becoming big business, and in the pursuit of new and innovative products and technologies, the access by growers to public varieties is gradually diminishing. If the playing field was level, the success of public varieties would lead to end–point royalties, which in turn would provide public breeding programs the ability to be competitive with their private counterparts. However with the development of hard–nosed companies as the new stakeholders of public resources (eg. University breeding programs), success does not necessarily beget success, in that the companies divert the funds of success into what they perceive as investment possibilities for the future, while the reinvestment into the breeding programs that procured these funds is to some degree ignored. In this sense profitability comes before public need, and the privatisation of what were previously public breeding programs is not directed to meeting the rights or needs of society as a whole.

It thus becomes the right of each society to decide what sort of a balance we need between public and private interests, and whether service to the community or to humanity should remain as an important part of plant breeding per se. In this respect I see biotechnology as part of the process of plant breeding, and hence apply the same questions of public versus private need to biotechnology, as well. As Borlaug points out "the more important matters of concern by civil societies should be equity issues related to genetic ownership, control, and access to transgenic agricultural products". He points out that "The affluent nations can afford to adopt elitist positions and pay more for food produced by the co–called natural methods; the 1 billion poor and hungry people of this world cannot. New technology will be their salvation, freeing them from obsolete, low–yielding, and more costly production technology….. If we fail to do so, then we will be negligent in our duty and inadvertently may be contributing to the pending chaos of incalculable millions of deaths by starvation"

FORGOTTEN TECHNOLOGIES

I also wish to argue that biotechnology is only part of the answer, and that at the end of the 20th Century and the beginning of the 21st, we have ignored some of the past priorities and technologies which remain essential components of rights of inheritance to future generations. These technologies can stand on their own, but better still interact with the new technologies to realise even greater benefits to mankind.

Germplasm conservation

At the top of this list I place germplasm management. Genetic diversity is at the heart of the survival not only of our crop species but of the human species as well. Germplasm conservation is about dealing with potential catastrophy. At the human level, some researchers have recognised that the rare cases of people who carry or are immune to the AIDS virus, may provide the key to finding a permanent solution to the destructive effects of AIDS. This is not the first or the last epidemic that has the potential to all but wipe out humanity, but it more than ever stresses the need for genetic diversity. With respect to crop species, blight has had devastating effects on crops, let alone the human population, with the potato blight in Ireland being the most severe. Scab is a serious problem worldwide, and more recently carnal bunt and Russian wheat aphid have had devastating effects. In almost every case resistances to these diseases have been found in the wild forms or distant relatives of our major crop species, and yet germplasm conservation does not have the glamour of either plant breeding or biotechnology, and does not necessarily attract the top scientific minds. Our University is one of the few institutes worldwide which actually teaches a course in Germplasm Management, and not just the conservation of germplasm, but the utilisation and conversion of germplasm into a useable form so that we have immediate access to such in the event of a major world catastrophy. I term this insurance breeding, because with an increasing world population, the effects of a single major epidemic to one of our major crop species would be devastating. This issue was well understood by the scientists at the N.I. Vavilov Institute during the 2nd World War, who could have saved their lives by eating the seeds of hope that were stored in their collections. It is a great tragedy that many collections of a diversity of species have been lost in recent times, and the two major Institutes for germplasm conservation in Poland need to be commended; one of these is housed here at Radzikow. One of the great tragedies in Australia is that valuable genetic and cytogenetic stocks are not conserved because there are no research outcomes or publications arising out of genetic conservation, and thus funding bodies are loathe to allocate funds for this purpose. We do not have the specialist resources to increase or maintain valuable cytogenetic stocks, and these are often permanently lost with the retirement of specialist staff members, who are frequently replaced, if at all, by specialists in another field. Due to urbanisation, war, and lack of adequate funding for germplasm conservation, many of these invaluable collections throughout the world have been permanently lost to mankind. Even with the new technologies, what has been lost can never be recreated.

Germplasm utilisation

This brings me to the second item on my list, namely the utilization of germplasm within breeding programs. When I started my triticale breeding program in 1975, I spent much of my early energies into enhancing the germplasm base within my breeding program. This period of consolidation is paying off handsomely today, as we are routinely developing new and improved cultivars. In the mid–seventies my initial focus was on the improvement of grain quality in triticale and I used a few smooth grained triticales based on *Secale montanum* as raw germplasm for the improvement of seed quality. This was not a quick process, and 20+ years on, the top yielding line at the NSW Agriculture trial at Cootamundra in New South Wales in 2000 was a line which included one of these smooth seeded sources in its pedigree. This new dual–purpose triticale may or may not have inherited its seed quality from *S. montanum*, but it is quite possible that its high vegetative biomass or aspects of its disease resistance did arise from its *montanum* source, considering that *S. montanum* is a perennial, and the resulting primary triticales and their progenies had excellent plant biomass. Too many plant breeders in the past have expected instant results from interspecific crosses of this nature, but the realities are that improvements take time, and I have always argued for cyclical systems for breeding and germplasm utilisation as part of any system for germplasm enhancement or even conventional plant breeding. The advantage of cyclical systems is that inputs produce throughputs and eventually outputs, and that these outputs become parents (inputs) in the next level of complexity or advancement in a germplasm enhancement or breeding program. Trethowan (1988) investigated one such cyclical breeding system, where lines were advanced up a hierarchial ladder from C to B to A according to the performance of mid–generation lines derived from crosses among all A (2–3) by B (10–15) combinations and from other crosses of all B lines with 5 C lines from the general germplasm pool. The B lines were ranked according to their A ´ B combining ability and by their B ´ C combining abilities. The best B lines showing superior rankings by both measures were then advanced to A lines and the best C lines advanced to B lines in the next crossing cycle, which was to be conducted every three years. The outputs from this program became new C lines which were included in the limited germplasm pool for breeding purposes. This approach was highly successful in terms of the ranked correlation coefficient among the B lines, and in terms of providing a cyclical defined breeding system. The same approach could be applied to germplasm enhancement, where the improved germplasm moves up the rungs on a ladder.

We will also be applying this same cyclical system to our hybrid triticale breeding program where we will be measuring our newly produced maintainer lines against a set of standard restorer lines for their general and specific combining abilities. It has taken us some years to develop our first stable male–sterile/maintainer combination with a very high general combining ability (GCA); this in turn will be crossed with other sources of maintainers and with other triticales which we have likewise identified as having high parent heterosis (HPH) in all or almost all of their crosses to other triticales. The top maintainer parents (A lines) will be identified on the basis of their high GCA, and intercrossed; it is the progenies of these intercrosses (B lines) that will be tested in the cyclical breeding scheme with a view to upgrading B lines to A lines. Hence there will be two sources of parent lines, newly identified A lines from the germplasm pool which are identified as having HPH, and progenies from crosses among the best A lines.

Cytogenetic manipulation

This leads me to the third item on my list, which is Cytogenetic Research. Although many of the resistances protecting our current wheat varieties against an assortment of diseases and pests are the result of cytogenetic endeavour, cytogenetic research has been dying for years, and there are few trained cytogenetic specialists, who are able to practice or teach their skills. Many of our current day molecular biologists do not understand cytogenetics, and although they may claim to be gene jockeys capable of isolating and inserting genes across species barriers, the cytogenetics approaches have been long proven to work, and although slow, are a sure and reliable way of transferring alien genes across species barriers. The new crop species triticale, is very much a product of cytogenetics, and much of its future development depends on the skills of researchers who are capable of recombining the best of wheat and triticale chromosomes. It is certainly hoped that the triticales of tomorrow will carry the quality characteristics of wheat, while at the same time carrying the superior yield and heterosis potential of triticale. We are only now beginning to understand the complexity of cell division, and the dynamics and physiology of cell growth. Just as we are able to transform genes coding for hormones to substantially increase the size of fish, there is a sort of inevitability about the discovery of systems for rapid cell growth in plants, thereby resulting in higher yields per unit time. The regulation of cell division is at the heart of this process, and the interaction of molecular biology with cytogenetics should do much to identify the genes responsible for rapid growth of cells, let alone the possibilities of inducing meiotic events in somatic tissues, thereby bypassing and speeding up the recombination process. Cytogenetics also carries the secrets to chromosomal and species evolution, and the identification and utilisation of gametocidal genes (Nasuda et al. 1998) should do much to speed up evolution within the laboratory. Gametocidal genes can be used to rearrange genes within and among the genomes of wheat and its relatives, and to induce all sorts of structural changes, which in the long run, by establishing new linkage groups and deleting/replacing/changing redundant or duplicate genes, provide the very essence of the mechanisms of evolution and speciation.

There are still many things that need to be done using conventional cytogenetic approaches eg. getting a better $1R^s$ segment in wheat with improved quality and/or yield and preferably with alternative rust resistance alleles, looking more carefully at the 6x triticales developed by Dr.F. Zillinsky in the late seventies which look a lot like octoploids and no doubt have several D genome chromosomes, making better use of the tetraploid (DDRR) triticales developed by Dr. Krolow in Germany, again with a view to improving quality parameters in triticale without significantly reducing yield or combining ability in hybrid combinations. Too much of this invaluable germplasm may simply be lost due to our failure to recognise the goldmines of future genetic research and cultivar improvement, which can be uniquely advanced by competent and innovative cytogeneticists.

Darvey (1984) proposed the establishment of an alien wheat bank as a system of preserving significant amounts of alien germplasm of known or unknown quality or quantity within a cross–pollinating wheat population through the use of chromosome pairing promoter genes, with a view to creating a reservoir of alien segments which have been successfully incorporated into wheat chromosomes. This system focused on one of the major objectives of germplasm management, namely the utiliza–

tion of alien resources for crop improvement. This was seen as an insurance against future epidemics; however in recent years there has been only limited funding for cytogenetic research even though the development of wheat lines carrying the dominant suppressor gene Ph^I derived from *T. speltoides* (Chen et al., 1994) would assist greatly in the achievement of this objective, which may also provide new opportunities for yield enhancement in wheat and its relatives.

A BROADER WORLD VIEW

The list of priorities can go on, and there are many technologies including tissue culture which can enhance the speed of plant breeding and be combined with mutagenic approaches to deliver significant benefits to plant breeding and to society as a whole. The world is going to face a major energy crisis in the years ahead, and we will need a renewable source of energy to drive our farm machinery so as to provide human food needs in the generations ahead. Plants are a wonderful source of renewable energy, both for methanol and ethanol production, and plant biomass and especially grain production from the cereals can potentially provide much of that energy; however research into the development of disease resistant perennial grain crops with high biomass production and low inputs in terms of land degradation and sustainability should right now be high priorities for the hopes of our future generations; however regrettably among governments there is often only a short term view, and society as a whole refuses to accept the rights of our children and our children's children. There are many good reasons for globalisation concerns in a world where many people are already hungry, and we need to make a commitment, not to making rich countries richer, but rather to making life more tolerable to those who are already on the planet and to look after the needs of future generations. We as agricultural researchers can do this by focusing on research projects that most effectively address human food needs as well as sustainability for future generations.

REFERENCES

Borlaug N. E. 2000. Ending world hunger. The promise of biotechnology and the threat of antiscience zealorty. Plant Physiol., 124: 487–490

Chen P.D., Tsujimoto H., Gill B.S. 1994. Transfer of Ph^I gene promoting homoeologous pairing from *Triticum speltoides* into common wheat and their utilisation in alien genetic introgression. Theor. Appl. Genet*.,* 88: 97–101

Darvey N.L. 1984 Alien wheat bank. Genetics: 107, 25

Nasuda S., Friebe B., Gill B.S. 1998. Gametocidal genes induce chromosome breakage in the interphase prior to the first mitotic division of the male gametophyte in wheat. Genetics*,* 149: 1115–1124

Trethowan R.M. 1988. Rapid breeding technology among hexaploid spring triticales. Ph.D. thesis. . The University of Sydney.

Walsch N.D. 1999. Applications for living. Published by Hodder and Stroughton. , 47–49.