Turk J Agric For
29 (2005) 105-111
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Role of Conventional Plant Breeding and Biotechnology in Future Wheat Production

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Received: 05.04.2004

Abstract: The global wheat production by year 2020 could be increased by 40% provided there is a good integrated multidisciplinary wheat research program optimally funded by either public or private sectors. More emphasis needs to be placed on: 1) Improving yield potential; 2) Durable disease resistance; 3) Increasing abiotic stress tolerance; 4) Adopting better conservation systems. There are roles for both conventional plant breeding and biotechnology supported by other disciplines to achieve this goal.

Key Word: Biotechnology, Transgenic, Green Revolution, Durable, Marginal Environments.

Introduction

The developing countries are projected to increase their demand for cereal grains by about 80% between 1999 & 2020 (Pinstrup-Anderson and Pandya Lorch, 1997). According to Rosegrant et al. (1997) that over the next two decades global demand for wheat could rise by 40%. By 2020, it is expected that 67% of the world wheat consumption will occur in the developing countries. The average wheat production in recent years has been between 590-600 million metric tons. By the year 2020, this amount has to be increased to a total of approximately 840 million metric tons and 66% of this has to be produced in developing countries. The Asian continent (West, Central, South and East) is the largest and most important region of globe for wheat production. At least 104 million hectares are planted to all kinds of wheats in these regions. Relative to Asia, the African continent and South America grow only 8 million hectares each. The current global average yield of wheat is approximately 2.5 tons per hectare. By 2020, this yield has to be increased to 4.2, if we are going to meet the global demand. This means an increase of 1700 kilograms per hectare. This is translated into an annual increase of 85 kilograms per hectare for the next 20 years. The issue is whether we have robust science and strong technology in place to handle such an enormous job. Note withstanding, that the role of governments and farmers is paramount to this issue; I have taken liberty to deal with only scientific issues which would affect productivity gains in the future.

The developed world is fully appraised of the situation and has strong public institutions and simultaneously permitted strong interventions of private enterprises. This two institutions are now working together, and the strong capital investment has permitted farmers to acquire heavy machineries which is critical to low cost agriculture such as zero tillage, residue management and timely operations for planting and harvesting. The market is fully develop based on quality and international trade criteria.

The situation in the developing countries is strikingly different. With the exception of a few such as China, India and Brazil, the investment in wheat research is low. In many instances the conventional plant breeding budget is let so low that most research infrastructures has become obsolete and non functional. The evolution of private sector in the developing countries compared to developed world has not occurred due to many causes but mainly due to less profit for seed industry.

Since rediscovery of Mendelian genetics, there have been technological breakthroughs which have been

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exploited in conventional plant breeding, such as hybrid vigor, polyploidy, biometry, chromosomal translocations and recently biotechnology. Each invention was incorporated into ongoing conventional breeding methodology. Perhaps amongst all, the application of mutation genetics was less successful for crop improvement even though parallel programs were setup in many countries. Does biotechnology require the same arrangement ? Many in the policy arena and donor group also believe that the vast exsitu collection of germplasm would solve the future food problem. Unfortunately, many such stored germplasm is in shamble, and unless vast resources are allocated for classification, quantification, genetic analysis and prebreeding, such germplasm is needlessly useless.

Not surprising, the most yield and associated advances in plant breeding has occurred due to incorporation of most advance gene pool in the breeding program (Rassmusson and Phillips, 1997). I personally and strongly believe that such trend in use of paramount germplasm would be the norm in the next 20 years.

So what role convention plant breeding would play in a highly charged biotechnological environments. Would there be resources for such undertaking. Perhaps not as much as it would be needed. The current conventional plant breeding is not a single discipline. It encompasses many related disciplines such as plant pathology, genetics, nutrition, soil and water and has incorporated many methodologies invented over 100 years. We would require a strong conventional plant breeding program to take full advantage of a strong biotechnology program. This is said so because a crop variety as products is outcome of multiple gene manipulation in one package. While looking into future, both conventional plant breeding and biotechnology would have a strong role in manipulation of genes toward achieving 830 million metric tons goal.

Green Revolution Continuum

The green revolution technology based on improved seed and optimum use of fertilizer, water, and other inputs, triggered the quantum jump in wheat productivity in many parts of the world and especially in South Asia. The storey of the green revolution has been amply documented. The process of change and maintenance of sustainable production and productivity were repeated subsequently in many environment including into rain fed agriculture such as Turkey, Argentina, Brazil & South Africa. In case of wheat and based on CIMMYT's monumental contribution to wheat research; the impacts of the collaborative improvement research done by CIMMYT and NARS (National Agricultural Research System) are documented by Byerlee and Moya (1993) and Heisey, Lantican and Dubin (2002). These studies cover a span of 30 years and clearly have established a role of improved germplasm in the sustainable agriculture especially in the area of averting large scale vulnerability caused by virulent pathogens.

Indeed many shortcomings associated with high input agriculture have been curtailed in the last 15 years. The devastating epidemics of first half of 20th century caused by rusts have been controlled through proper gene deployment in cultivars. The current varieties of wheat are not only input responsive but are also input efficient, offering better stability of production performance in farmers domains. Conway (1997) dubbed such interventions as doubly green revolution.

The impact data presented by Byerlee and Moya (1993) and Heisey et al. (2003) attribute a very large economic benefits in all wheat mega environments (Rajaram et al., 1995). Many believe that the impact of the green revolution has been only marginal and limited to the well watered area of the world. These two impact studies prove otherwise and the results of these are presented in Tables 1 and 2, respectively. These studies describe the multi phase adoption of wheat varieties bred by International Agricultural Research Centers (IARC) and National Agricultural Research System (NARS). At CIMMYT, there were many scientist involved during this period, however, it is worthwhile to mention that Norman E Borlaug and Sanjaya Rajaram provided the guidance, and leadership and took primary responsibility of execution of breeding programs from the beginning until year 2002. Within this period NARS scientists selected at least 500 cultivars of direct CIMMYT origin and bred an additional 1000 varieties through their own intervention but based on CIMMYT germplasm. The economic impact if these varieties have been between 1.5 to 3.0 billion additional dollars to the farmers in the developing countries.

Table 1. Estimated effects of spring wheat breeding research on production in the post-Green Revolution period, 1977-90

	Sub-Saharan Africa	West Asia/ North Africa	South Asian	Latin America	All
Total production increase in 1990 (million t)	0.15	2.45	9.34	3.4	15.34
Percent production increase due to Stage 1 adoption (b)	57	43	17	53	29
Average wheat price ($1990/t)	210	210	195	195	198
Total value of production increase in 1990 (US$1990 millions) (a)	31	515	1822	662	3030
Percent germplasm of CIMMYT origin (c)	39	52	44	60	49
Value of production increase attributed to CIMMYT (US$1990 millions) (c)	12	268	802	397	1485

a. Excludes winter/facultative wheats.
b. Stage 1 corresponds to the first adoption of Modern Varietis.
c. Varieties released since 1972 are weighted as follows: CIMMYT cross, 0.85; NARSs cross with CIMMYT parent, 0.50.
Source: Byerlee and Moya (1993)

Table 2. Annual benefits from wheat improvement research in the developing world attributable to the CIMMYT/NARS system, simple gross annual research benefits assumption.

Assumed yield gain from MVs (t/ha)	Additional annual production (million/t)	Value of additional production (billion 1990 U.S.$)
0.2	16.7	1.6
0.3	25.1	2.4
0.4	33.4	3.2

Note: Area planted to modern varietis (MV's) is 83.6 million hectares; the assumed price of wheat is US$97/t (1990 dollars, equivalent to US$ 120/t 2000 dollars).
Source: Heisey et al.(2002)

Status of Genetically Modified Crops (GM)

The invention and application of biotechnology in crop breeding have been strong. The developed world grows 42.7 million hectares of transgenic maize, soyabeans and cotton compared to 16.0 million hectares in the developing countries (Figure 1. James, 2002). In the developed world, the large multinational companies invested heavily on transgenic research, even though the US venture capital investment in agricultural biotechnology is slowing down (McElroy, 2003). One good lesson for the developing countries policy makers is that the investment in biotechnology was not done at the expense of conventional plant breeding. Indeed, certain multinational bought many seed companies in 1990s which are very strong in conventional plant breeding. It is my opinion that GM wheats would enhance disease and insect resistance and encourage adoption of conservation agriculture in the developing countries.

Enhanced Yield Potential

In CIMMY wheat breeding program (1962-2002), there has been continuous grains in yield potential through utilization of paramount germplasm and special

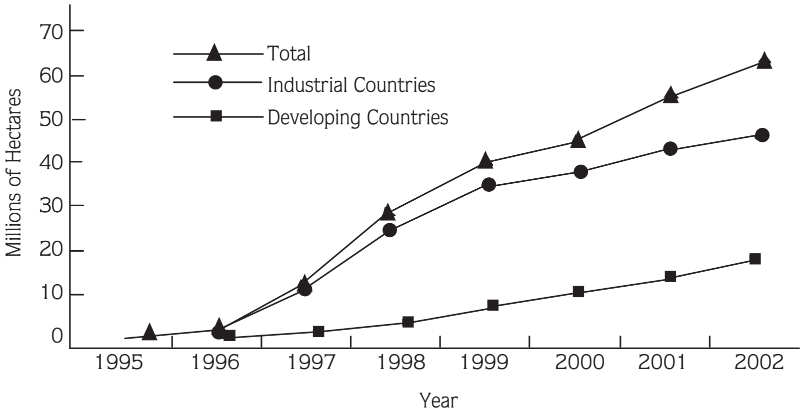

Figure 1. Global Area of Transgenic Crops, Millions of Hectares (1996-2002) Source: James (2002)

genetic stocks as illustrated in Figure 2. The graphic illustrates the yield performance of a group of varieties including Penjamo 62 bred in 1962 and Kambara derivatives based on variety Baviacora produced in late 1990s. Penjamo 62 was derived from special genetic stock Norin 10-Brevor while Baviacora is a derivative of other special genetic stock Veery with 1B1R translocation. The synthetic wheats (derivatives of Triticum tauschii x Durum wheats) have contributed genes for enhanced yield potential as well. The recently bred Lr 19 genotypes have given further boost in yield potential (Table 3, Reynolds et al. 2001). The use of paramount germplasm and special genetic stocks have been responsible to provide continuing breakthroughs in yield potential grains, at the rate of 100 kilogram per hectare per year over 38 years period (Figure 2).

Based on the preliminary data available through this author that the future wheat cultivars may bear larger spikes, larger number of grains and larger seed. These superior traits, if properly combined, may produce

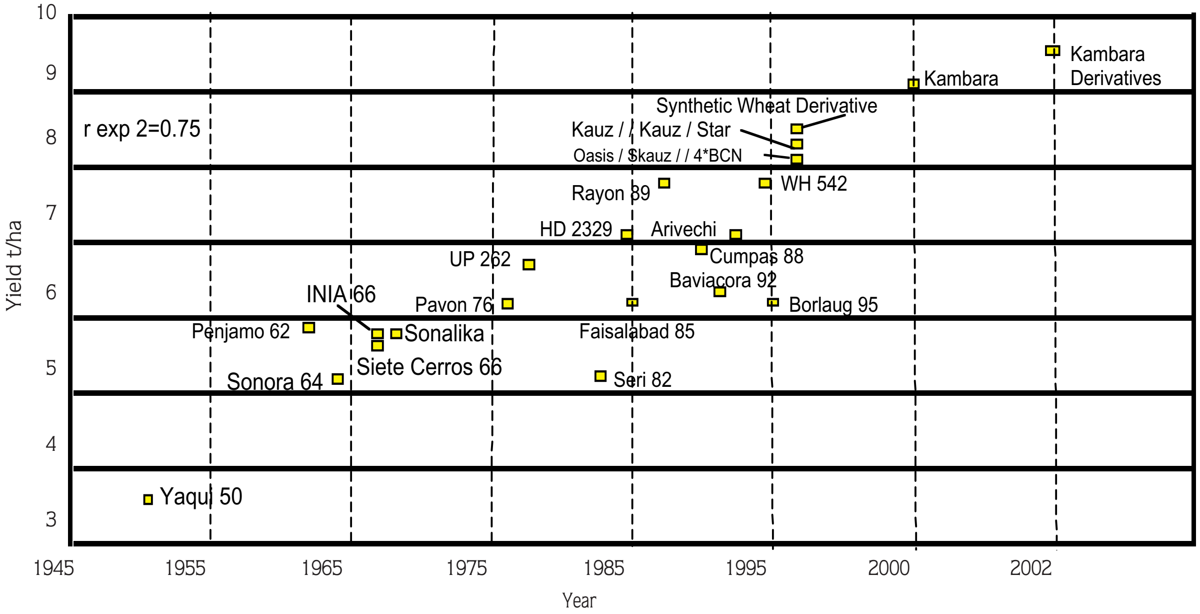

Figure 2. Yield vs. year of release of wheat varieties at Ciudad Obregon, Mexico. Source: S. Rajaram (2002, unpublished)

Table 3. Biomass, yield and yield components for *Lr19* insolines in spring wheat backgrounds, averaged over two cycles, Ciudad Obregon, Sonora, Mexico, 1998-2000

		Biomass (g/m^2)	Yield (g/m^2)	No.grains (per m^2)	Grains spike	Kernel wt (mg)
Main effect						
Lr19		1560	670	17700	44.4	38.3
Control		1440	610	15600	39.9	39.4
P Level		0.001	0.001	0.001	0.001	0.05
Background	Lr19					
Angostura	+	1575	630	15500	37.9	40.9
Angostura	-	1435	585	13000	36	44.9
Bacanora	+	1495	645	18700	50.5	34.4
Bacanora	-	1525	620	17500	43	35.6
Borlaug	+	1720	755	19900	48.5	38.2
Borlaug	-	1520	630	17300	37.9	36.5
Star	+	1630	690	18500	43.9	37.2
Star	-	1590	640	17400	39.7	37.0
Seri	+	1600	675	18400	47.4	36.6
Seri	-	1420	630	16000	45.3	39.6
Yecora	+	1350	655	15300	38.4	42.6
Yecora	-	1180	545	12700	37.5	42.9
P level (interaction)		0.05	0.05	ns	ns	0.1

Source: Reynolds et al. (2001)

further breakthrough in yield potential to the order of 15-20 % over Kambara derivatives. The preliminary evidence of such breakthrough is evident in small program managed by this author in North Western México.

Breeding Durable Diesease Resistance

Until a quarter of a century ago, wheat rusts the most serious and economically important diseases of wheat, periodically devastated wheat production. This happened every time that susceptible varieties, favorable environmental conditions and pathogen adaptability to create large scale epidemics. The Yaqui Valley in Sonora, Mexico, witnessed rust epidemic continuously in 1970's and early 1980's.

Starting in the 1950's, the CIMMYT wheat program (rather its predecessor, the office of Special Studies) led by Dr. Norman E Borlaug used in its breeding efforts the durable stem rust resistance of Hope (Sr 2 complex), a variety bred by Mc.Fadden in South Dakota State, USA., and the durable leaf rust resistance of Frontana a Brazilian variety.

Based on CIMMYT's research over the last 30 years, our national program partners have released over 500 bread wheat cultivars and many of these trace their durable rust resistance to Hope, Frontana and other diverse sources. This resistance is conferred by minor genes that interact additively to protect the crop from rust pathogen. Most importantly, the resistance conferred by minor genes is durable (historically), which phenotypically results into slow rusting (dilatory) with negligible effect on yields.

Farmers all over the world have reaped the economic benefits of the disease resistant cultivars, which produce the same yield with and without fungicide protection (Figure 3). In a recent study on the benefits of incorporating leaf rust resistance into modern varieties, Smale et al. (1998) estimated that gross benefits generated in the Yaqui Valley from 1970 to 1990 through the incorporation of diseases resistance totaled US $17 million (in 1994 real terms).

Despite great advances in breeding for durable leaf rust resistance at CIMMYT, it is still too early to say whether we can bring global stability to rust resistance. In early 1990's, a virulent stem rust race devastated variety Enkoy in Ethiopia and losses were estimated to be up to 40 million US dollars. During 1990's stripe rust has been pandemic from Pakistan to Egypt including Iran, Turkey and other middle eastern countries. In 2001 and

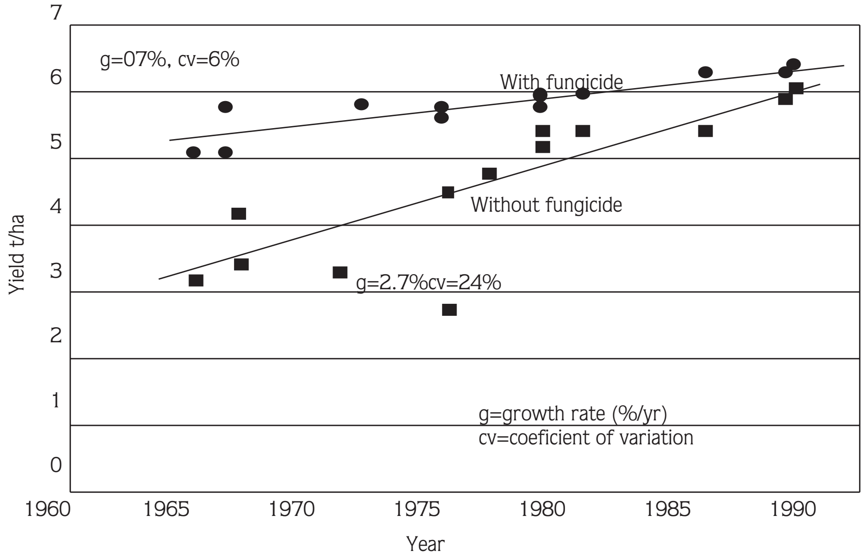

Figure 3. Yield of historically important varieties (released 1964-86) with and without fungicide, Ciudad Obregon, Mexico, 1990-91 Source: Sayre et al. (1998)

2003 a virulent leaf rust on durum wheats devastated most of the advanced lines in CIMMYT program and caused a severe epidemic in Yaqui Valley. It was averted only through large scale application of fungicides in 2003 over 110 000 hectares with estimated cost of 9 million dollars. The 2001 epidemic in Yaqui Valley resulted also a massive fungicide application to avoid disaster. The stripe rust threat in Central Asia is real and endemic.

For many years, I have advocated the alternative sources based on durable resistance, and incorporate these into most adapted varieties. The molecular markers can help to select some of these genes.

Moving Beyond Marginal Yields in Marginal Environments

Limited water availability is probably the most common stress that affects farmers in marginal environments, but they also have to contend with factors such as diseases, acidity, extreme temperatures, water logging, mineral deficiencies and toxicities. A region is defined as marginal when wheat production drops to 70% of optimum yield levels (Evans and Fischer,1999), as in, for example the highlands areas from Turkey to Afghanistan, the dry land areas of West Asia and North Africa (WANA), much of Ethiopia and the dry land areas of central and southern India. Northern Kazakhstan is an extreme case of drought region. At least 45% of total 119.3 million hectares in the developing countries are classified marginal (Table 4).

I had proposed a breeding system for CIMMYT wheat program in which yield responsiveness is combined with adaptation to drought conditions. Because most semiarid environments differ significantly in annual precipitation distribution and amount, it is prudent to construct a genetic system in which plant responsiveness provides a bonus whenever higher rainfall improves the production environments.

Table 4. Portions of wheat producing regions of the developing world that are defined as marginal

Region	Total Wheat area (000 ha)	Percent Marginal
West Asian/North Africa	28,300	65
Central Asia and the Caucasus	15,000	80
South Asia	34,500	35
East Asia	30,100	13
Eastern Africa	1,500	27
Southern Africa	1,300	91
Southern Cone of South America	7,400	60
Andean Region of South America	300	18
Mexico/Central America	900	43
Total	119,300	45

Source: Reeves et al. (1999)

Why do I believe that this can be done? One compelling piece of evidence comes in the form of variety Veery which combines high yield performance in favorable environments and adaptation to drought in more marginal areas. The variety Baviacora and its derivatives such as Weebil and Kambara whose origin trace back to Veery even fits better into this model. It has been suggested in various literatures that yield potential per se would buffer better in droughty marginal environments. This does not appear to be so, because many high yielding genotypes well adapted to optimum environments show very poor performance in drought condition. The genotypes like Baviacora and derivatives show exceptional performance in both conditions which indicate that responsiveness and drought adaptation genes are imbedded in the same genetic system. The adaptation to drought in Baviacora is highly inherited because only one limited back cross was used to derive lines such as Weebil and Kambara which combine the recipient parent's characteristics of high yield and adaptation to drought and shows durable leaf rust resistance.

The region of Central Asia is highly variable to annual precipitation and can benefit an implementation of such breeding scheme to improve genotypic performance. CIMMYT has catalogued many sources of drought adaptation genotypes such as 1B1R translocation (Villarreal et al., 1995) and Triticum tauschii derived synthetic hexaploid wheats (Rajaram et al., 2001).

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