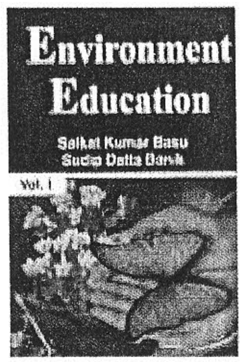

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"Ecosystem is the complex network of interactions between living things and their physical as well as biological environment. For humankind, this complex is further extended for social, cultural and psychological components of environment. Population, organization, environment and technology are the four major components of ecosystem. Human population density and human behaviour add further dimensions in studying environmental perspectives and human responses. Three essential components of environment air, water and land, technically known as atmosphere, hydrosphere and lithosphere altogether comprise biosphere. Physical and biological factors of environment influence the survival, growth, development and reproduction of organism. Pollution in biosphere caused by the agents affect the life of organism and dissolute ecological balance. The present volume inscribes the different facets of anthropogenic impacts on environment. Pollutants mostly generated by human activities indiscriminate use of non biodegradable substances, chemicals, industrial wastes, and others debase the natural values of environment and ecology.

Environmental scientists monitor the quality of the environment, interpret the impact of human actions on ecosystems, and develop strategies and management procedures for restoring balance in ecosystems. Environmentalism is a broad philosophy and social movement focused on a chief concern for the conservation and improvement of the natural environment and human civilization. This present peer reviewed publication, environment education: global issues and policies is our third venture in this subject of editing a scientific volume. A galaxy of outstanding contributions by the eminent scientists and environmentalists from different parts of the world has enriched the volume. We are grateful to the authors of this volume. They have turned our long fostered dream of having this kind of fascinating volume into reality." (jacket)

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Varshney, C. K. 1991. Water pollution and management. Wiley Eastern Ltd., New Delhi. systems, wild raspberry, pesticide-free cultivated raspberry, and commercial raspberry treated with a variety of pesticides, were sampled at frequent intervals.

Whitford *et al.* (1987) Spider community - hunting guild - Carbaryl and fenvalerate Only tetragnathidae were reduced Field- survey USA Action sites of adult European corn borer (ECB), Ostrinia nubilalis (Huebner).

CHAPTER-VII

Economic Impact of Wheat Rusts and Benefits of Breeding for Genetic Resistance to Sustainable Food Production

Márcia Soares Chaves[1]

José Antônio Martinelli[2]

Sandra Mansur Scagliusi[1*]

Sandra Patussi Brammer[1]

[1]*Embrapa - National Wheat Research Center, Rodovia BR 285, Km 294, 99001-970 Passo Fundo/RS, Brazil*

[2]*UFRGS – Federal University of Rio Grande do Sul, Av. Bento Gonçalves, 7712, 91540-000, Porto Alegre/RS, Brazil*

[*]*corresponding author*

"...you cannot build peace on empty stomachs"
Lord John Boyd Orr, First Director General of the FAO
Nobel Peace Prize winner in 1949
(from Reynolds & Borlaug 2006)

ABSTRACT

World food security will depend on increased production of three major cereal crops – wheat, rice and maize. Of these, wheat is of great importance in terms of tonnage and financial value. Rust diseases are the most significant constraint to increase wheat production because they can reduce grain yields substantially or even totally. Genetic resistance is a better mean of controlling these pathogens, especially in developing countries, where the use of fungicides and pesticides to sustain yield is

prevalent. Breeding for resistance to rust diseases in wheat is an example of productivity maintenance research; and the increases in productivity resulting from the widespread use of modern varieties in the post-Green Revolution period would not have been possible without incorporating and maintaining this trait in wheat crops. Substantial economic returns were estimated by valuing the yield losses avoided through rust resistance and the social consequences for not having resistance were projected as catastrophic for farmers and societies relying extensively on wheat crop. Despite the success of international wheat breeding improvement effort hunger still looms large for many poor people to this date, particularly in developing and underdeveloped countries. Fortunately, new and more accessible genetic tools and a new generation of quantitative tools may help scientists to face the ever greater challenges associated with population growth, highly heterogeneous and unpredictable environment.

INTRODUCTION

Modern agriculture feeds 6,000 million people today, and 60 % of food supply is provided by three cereals - wheat, rice and corn - which are now the three more abundant plants in the planet (Tilman *et al.* 2002). Of these, wheat is the more important cereal crop in Northern hemisphere, as well as in Australia and New Zealand, although it is cultivated in all continents. Major wheat producing countries are China, India, the USA, France and Russia (Oerke 2006).

Wheat productivity increased significantly during the past century as a result of the adoption of technologies available after the so-called Green Revolution, as modern improved varieties, mechanization, more effective pest and disease control, best production practices and better farm management (Dixon *et al.* 2006). Today, the world production reaches about 630 million tons (FAO 2006). The long run evolution of wheat productivity during 1900 to 2000 is shown in *Fig. 7.1*. The initiation of yield growth was in the third and fourth decades of the 20th century, and the average national wheat yields in major wheat producing countries grew steadily during the second half of the century, with the adoption of modern varieties in the 1960s (Byerlee 1996; Dixon *et al.* 2006). These improved varieties of wheat have spread widely and quickly than any other technological innovation in the history of agriculture (Dalrymple 1985).

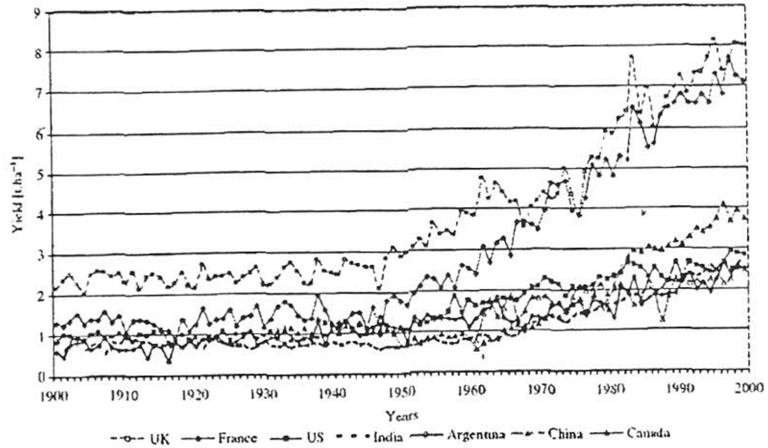
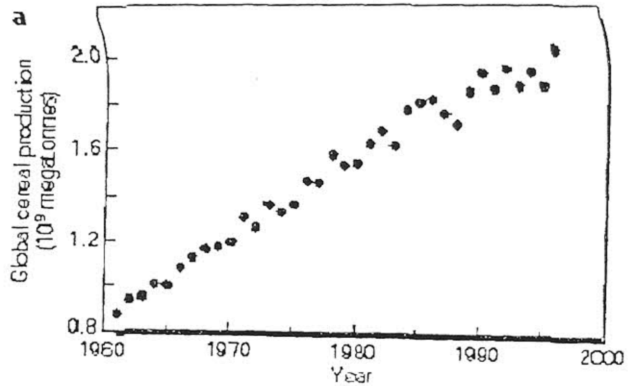


Figure 7.1. Long run wheat yields 1900-2000 (Dixon *et al.* 2006).

Despite the success of Green Revolution, Norman Borlaug predicted in his Nobel Peace Prize acceptance speech in 1970 that it would reach a temporary success in man's war against hunger, and if technologies would completely implemented, it could provide sufficient food through the end of the 20th century (Reynolds & Borlaug 2006); and unless demographic growth was brought in proportion with the food production capacity of the world there was a very real threat that the Malthusian prediction would come true (Rajaram 2001). In fact, demand for wheat in developing countries is projected to increase significantly in the next 20 years. Today, about 300 million tons of wheat are produced at developing countries, and by 2020 it is estimated that will be necessary 440 million tons to supply the demand generated by ever increasing population in the developing world (Trethowan *et al.* 2005). By 2050, world population is projected to be 50 % larger than at present and the global grain demand is projected to double. Over the next half century it is predicted that the global demand for cereals will increase by approximately 60 % and developing countries will account for 93 % of cereal-demand growth (Rosengrant & Cline 2003).

With the increase of world population and with the issue of food security projected to be ever more critic, the eradication of hunger and poverty was included as one of the United Nations Millennium Development Goals, adopted in 2000 (Rosengrant & Cline 2003). To achieve this goal, the yield potential of cereal crops stays as a high priority subject. However, the current scenario illustrates a potential instability of the global strategy of food production, where only three crops are responsible for such high proportion of production, and, on an epidemiological context, the risk of plant disease epidemics assumes equally a high probability (Tilman *et al.* 2002). In environments characterized by dense stands and high tiller density, the foliar diseases caused by obligate parasites with a high evolutionary rate, as wheat rusts, are the most important yield constraints (Duveiller *et al.* 2007). So, doubling food production again and sustaining food production at this level are major challenges; and doing so in ways that do not compromise environmental integrity and public health is a greater challenge. This is ever more serious considering that in the past few decades the increase in cereal production was accompanied by the increase in pesticides production and commercialization (*Fig. 7.2*; Tilman *et al.* 2002).



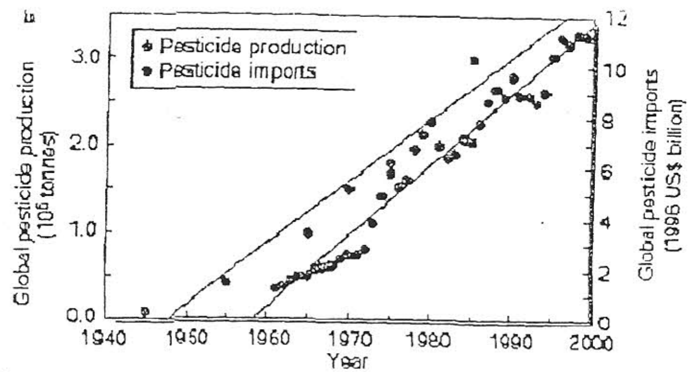


Figure 7.2. Agricultural trends over the past 40 years. a) Total global cereal production, b) Total global pesticide production and global pesticide imports (modified from Tilman *et al.* 2002).

Genetic resistance remains the better option for controlling wheat rusts, especially in wheat-producing areas of developing countries, where the use of fungicides and pesticides to sustain yield is prevalent. This practice has significant impacts on plant biodiversity, on human health and on the costs of controlling disease outbreaks, which are relatively high (Germán *et al.* 2007; Samale *et al.* 1998; Trethowan *et al.* 2005). Improvements in productivity therefore require more efficient and sustainable use of available resources; improving the durability of genetic resistance will influence the health of entire ecosystem (Trethowan *et al.* 2005).

Breeding for resistance to rust diseases in wheat is an example of productivity maintenance research. Unlike research that enhances productivity by increasing crop output for a specific quantity of input, maintenance research counteracts crop losses that result from changes in the biological or physical environment. Productivity enhancement is measured in terms of positive yield gains, associated with research investment; productivity maintenance must be estimated in terms of the yield losses that would be occurred in the absence of the research investment (Samale *et al.* 1998).

YIELD LOSSES TO WHEAT RUSTS

Leaf rust caused by *Puccinia triticina* is a wheat disease of major historical and economical importance worldwide (Roelfs *et al.* 1992; Saari & Prescot 1985; Samborski 1985). It is the most widespread of the three types of wheat rusts. The other two are stem rust caused by *Puccinia graminis* and stripe rust caused by *Puccinia striiformis*. Historically, cereal rusts diseases were clearly of major significance but estimation of yield losses received attention only in the 20th century due to a better understanding of disease biology and increasing need to appraise economically the financial investment in control programs.

Losses due to the cereal rusts in the United States of America from 1918 to 1976 were compiled by Roelfs (1978). In epidemic years yield reductions due to stem rust (*Puccinia graminis* f.sp. *tritici*) and leaf rust (*Puccinia triticina*) were of 50 % or more. Stripe rust (*Puccinia striiformis*) was more restricted in distribution, even though losses up to 70 % in commercial fields were recorded. Green & Campbell (1979) estimated that the protection of wheat cultivars resistant to stem rust grown in risk areas of Canada valued at C$ 217 million annually. Wiese (1977) reported that during the 1960's the rusts were estimated to have reduced North American Wheat yields by over 1 million tones (2 %) annually.

Stem and leaf rusts epidemics also have caused series damage in Australia. In 1880s, there was a sequence of severe epidemics that resulted in sufficient public concern and subsequent political pressure to establish State Department of Agriculture in New South Wales and Victoria. Estimates of crop losses due to wheat rusts varied from 30 % in leaf rust susceptible cultivars (Rees & Platz 1975) to 55 % in wheats susceptible to both stem and leaf rust (Keed & White 1971). Wellings *et al.* (1985) reported that in New South Wales, field plots of commercial cultivars with relatively low levels of natural leaf rust infection were shown to sustain up to 15 % yield loss. A widespread leaf rust epidemic in Western Australia in 1992 caused yield losses of up to 37 % in susceptible cultivars with average losses of 15 % across many fields. Economic evaluations of national losses have also ranged from A$ 100-200 million due to the 1973 stem rust epidemic to an estimated A$ 8 million cost of chemical application for disease control during an epidemic of stripe rust in 1983 (McIntosh *et al.* 1995; Wellings & Luig 1984). An economic analysis of losses due to a range of wheat diseases in Australia (Brennan & Muray 1988) estimated that the annual value of control strategies for stem, stripe and leaf rust was A$ 124, 139 and 26 million, respectively. These estimates represent the annual national benefits derived primarily from resistance breeding activities directed towards the control of wheat rusts.

In South America, leaf rust is currently the most prevalent and severe wheat disease. A very high proportion of the wheat area is planted with susceptible or moderately susceptible cultivars, allowing widespread local oversummering and early onset of epidemics in the growing season. Losses caused by leaf rust can be over 50 % in severe epidemics if fungicides are not used. Losses estimated at US$ 170 million were caused by epidemics on 10 important cultivars grown in the region during the period 1996-2003. Considering the large areas sown to cultivars that require chemical control in an average epidemic, the total annual cost of fungicide applications to control leaf rust in the region is about US$ 50 million (Germán *et al.* 2007). Stripe rust is more important in the wheat area

in southern Chile, where a severe epidemic occurred in 1940. During 1976-1988 stripe rust caused economic losses at least once every 2 years (Andrade 1990). Although stripe rust infections have not caused major concern over the past few years, an early epidemic in 2001 affected several spring cultivars (Germán *et al.* 2007). Incidence of stem rust historically has been more sporadic, but it caused higher levels of damage during severe epidemics. It was considered the most destructive wheat rust in Brazil, Paraguay, Uruguay, the northern wheat growing area of Chile and the northern and central north wheat area of Argentina. A very severe epidemic occurred in Argentina and other Southern American countries in 1950 (Antonelli 2000). During 1975-1976 widespread epidemics occurred in Brazil, Argentina and Uruguay, even under unusually favorable environmental conditions. For over two decades wheat stem rust has not been severely epidemic, but during 1975-2003, two stem rust epidemics were observed in Brazil and localized epidemic outbreaks occurred during the 1990s on some widely grown cultivars in Paraguay (Germán *et al.* 2007).

Yield losses due to cereal rusts have also been reported from the Indian subcontinent and the Middle East. Severe epidemics of cereal rusts have been recorded in India since the early of 1800 (Joshi 1976). In Pakistan, a severe leaf rust epidemic in 1978 resulted in an estimated national loss of US$ 86 million (Hussain *et al.* 1980). In Egypt, crop losses due to leaf rust infection were up to 50 % (Abdel Hak *et al.* 1980). In Europe, stripe rust and leaf rust are mostly associated with cereal rust losses. Priestley & Bayles (1988) estimated that losses in susceptible winter wheat varieties due to stripe and leaf rusts were of £83 million with the value of resistance estimated at £79.8 million. In China, winter wheat production also is affected by recurrent epidemics of stripe rust. Epidemics in 1950, 1964 and 1990 were estimated to have caused losses of 6, 3 and 2.5 tones, respectively (MacIntosh *et al.* 1995).

In the late 1980s, a new race of stripe rust evolved in eastern Africa and migrated to South Asia through Middle East and West Asia in about 10 years, causing severe epidemics and crop losses over US$ 1 billion in its migration path (Singh *et al.* 2004). In 2007 and beyond, the world could be facing an even more devastating situation with the outbreak of stem rust race Ug99 in eastern Africa. Race Ug99 was initially detected in Uganda in 1999, then in Kenya in 2002-2003 and soon after in Ethiopia in 2003-2004. Because most of leading cultivars and lines tested in Kenya and Ethiopia are susceptible severe epidemics have been reported and the migration of this new race to neighboring areas and beyond has been motive of great concern (Expert Panel on Stem Rust Outbreak in Eastern Africa 2005). Damages could total US$ 1-2 billion in Asia alone, based on a 10 % yield loss estimate and depending on market price. In response to this new threat to food security, a Global Rust Initiative has been launched during 2005 and led by CIMMYT (International Wheat and Maize Improvement Center) in partnership with ICARDA (Center for Agricultural Research in the Dry Areas) and various National and Advanced Research Institutions. The strategies to reduce the possibilities of major epidemics include monitoring the spread of race Ug99 beyond eastern Africa, massive testing of advanced lines in East Africa accompanied by an emergency crossing program to achieve satisfactory levels of resistance. Up to now, a few wheat genotypes that combine resistance and high yield potential have been identified but need rigorous field testing to determine their adaptation in target areas (Duveiller *et al.* 2007; Singh *et al.* 2006).

BENEFITS OF BREEDING FOR GENETIC RESISTANCE TO SUSTAINABLE WHEAT PRODUCTION

One of the first demonstrations of the possible genetic manipulation of plant disease resistance occur in 1905, when Biffen (1905) showed that resistance in wheat cultivars to stripe rust was simply inherited. Since then, host resistance has become one of the primary control methods of plant diseases and a priority objective of plant breeding (Byerlee 1996). This form of control is relatively inexpensive for plant producers to implement and is reported to be more environmentally friendly than some other control strategies (Bockus *et al.* 2001).

Varieties can carry different types and levels of leaf rust resistance. With the discovery of the genetic basis of resistance (Biffen 1905), physiological specialization in rusts (Stakman *et al.* 1962), and the gene-for-gene hypothesis (Flor 1956) the utilization of race-specific resistance has dominated in wheat improvement. Particularly for the cereal rusts, race-specific resistance genes often break down with exposure to the rust pathogen, contributing to a "boom-bust" cycle of resistance and associated genetic vulnerability because of shifts in the pathogen population (Samale

et al. 1998). The likelihood of resistance breakdown increases considerably if these race specific resistance genes are the only source of resistance in cultivars releases to farmers. It has been well documented that race-specific resistance genes typically breakdown within 5 years of deployment (Singh & Huerta-Spino 2001). Race-nonspecific resistance proposed by Vanderplank (1963) and applied to leaf rust resistance by Caldwell (1968) has been the dominant method used by International Wheat and Maize Improvement Center's (CIMMYT) wheat-breeding programs. Genes conferring race-nonspecific resistance to leaf rust in wheat have partial and additive effects, and although the response to infection is essentially susceptible, the rate of disease progress is slowed. Geneticists and pathologists at CIMMYT believe that adequate levels of nonspecific resistance can limit disease losses to insignificant levels in farm fields and is more likely to endure for many crop seasons (Samale 1998). This long term resistance is extremely relevant the developing world, where many countries do not yet have efficient seed production and variety replacement capacity (Trethowan *et al.* 2005).

During the past 40 years, a collaborative network of publicly funded international wheat scientists played a central role in providing food security in the developing world. Thanks to a continuing stream of high-yielding varieties combined with improved crop management practices, food production has kept pace with global population growth (Reynolds & Borlaug 2006). Between 1966 and 1990 the number of varieties released by national breeding programmes doubled and the proportion of releases that were products of international collaboration was over 0.7 (Byerlee & Moya 1993). The area occupied with modern varieties increased steadily from 12 million ha in 1970 (0.2 % of the total wheat area in the developing world) to 50 million ha (0.7 % of the total area excluding China) in 1990. In terms of yield increasing in farmers' fields the most comprehensive data come from irrigated regions where gains have averaged just over 1 % per annum between 1965 and 1995. Data from more marginal environments indicate even great yield progress (2-3 % per annum) in both semi-arid and heat-stressed environments between 1979 and 1995. A rough estimation of the economic gains associated with adoption of modern varieties of spring bread wheat between 1977 and 1990 indicated that they were associated with an additional 15.5 million tons of wheat in 1990 alone, worth approximately US$ 3 billion, while the estimated investment in all international wheat research was US$ 100-150 million annually in 1990. A more recent analysis estimated that the impact of modern varieties in 2002 was equivalent to an extra 14-40 million tons of grain per year, using the most conservative and the most liberal scenarios, respectively. This translates into an extra value of US$ 2-6 billion annually (Reynolds & Bourlaug 2006).

Gains in yield would not have been possible without incorporating and maintaining genetic disease resistance to rusts and other wheat diseases, because they can reduce grain yields substantially or even totally. International wheat breeding has placed great emphasis on breeding for genetic control of disease with two important spin-offs: the farmer is protected from uncertainty and the environment sustains a lower agrochemical burden (Byerlee 1996). Research at CIMMYT indicates that over the past few decades the impact of breeding for genetic resistance has generated a large proportion of the global economic return to investment in international wheat research (Byerlee & Traxler 1995; Reynolds and Borlaug 2006). For example, the benefits of incorporating nonspecific resistance to leaf rust caused by *Puccinia triticina* into modern bread wheat have been estimated using data on resistance genes identified in cultivars, trial data and area sown to cultivar in Yaqui Valley, Sonora State, Mexico. In the most pessimistic scenario, the gross benefits generated from 1970 to 1990 were US$ 17 million (in 1994 real terms). Even when costs were overstated and benefits were understated, the internal rate of return on capital invested was 13 %, well within the range recommended for use in project evaluations by the World Bank (Samale *et al.* 1998). The economic benefits of maintenance research are also report as large by Marasas *et al.* (2003). The authors indicate that the internal rate of return on CIMMYT's research investments in breeding for leaf rust resistance spring bread wheat was estimated at 41 % and the net present value (discounted at 5 %) at US$ 5.36 billion (at 1990 dollars), with a benefit-cost ratio of 27:1.

Improved varieties not only have the potential to increase yields but also increase grain and end-product quality. They also have the potential to lower the consumer prices and lessen environmental degradation (Dixon *et al.* 2006). As a matter of fact, another way to look at the impact of the Green Revolution is to consider its positive environmental impact. Had the global cereal

yields of 1950 prevailed 1999, an additional of 1.8 billion ha of land of the same quality would have been required – instead of the 600 million that was used – to equal the current global harvest (Fig. 3). Obviously, such a surplus of land was not available, and certainly not in Asia where the population has increased from 1.2 to 3.8 billion over this time period. Moreover, had natural ecosystems been brought into agricultural production, the environmental consequences would have been losses of biodiversity with extinction of some plant and animal species. Worst still, many of these soils are unproductive and/or fragile, and the latter would have experienced irreversible soil erosion and desertification in drier regions, as has occurred throughout history where fragile lands have been over-cultivated (Reynolds & Borlaug 2006).

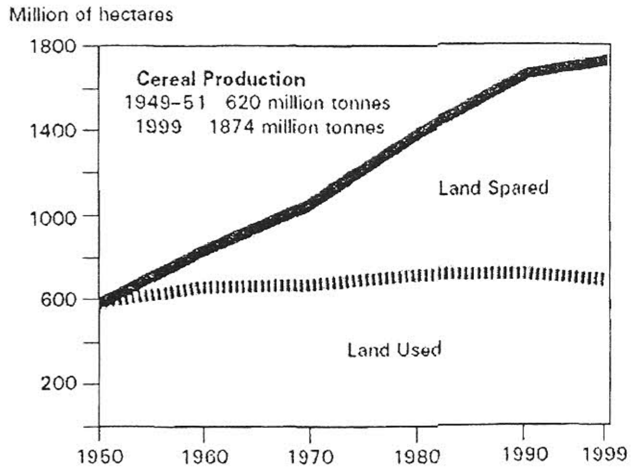


Figure 7.3. Land saved due to increased yield of modern wheat varieties (assuming the land area that would have been required to meet growing world cereal production if 1950 yields had prevailed through 1999; Reynolds & Borlaug 2006).

FUTURE CHALLENGES AND POTENTIAL OF BIOTECHNOLOGICAL TOOLS

In spite of the impact caused by the Green Revolution and the success of international wheat breeding programs occurred after it (post-Green Revolution period), close to 2 billion people are still suffering from the lack of healthy and safe food and about 800 million of them are chronically under nutrition (Fresco & Baudoin

2002). Since the beginning of agricultural production, there has been a continuous effort to grow more and better quality food to feed ever growing populations. Although Malthus's predictions have been proved to be real for many poor countries, where people subsist on what they grow for themselves, Malthus underestimated the importance of technological change, which has increased productivity in agriculture at a *geometric* rate rather than an arithmetic one, and a rate far higher than the rate at which the demand for food has been growing in most advanced countries (Lipsey & Chrystal 2007). However, his predictions continue to alarm agricultural researchers, especially plant breeders, seeking new technologies that will continue to allow us to produce more and better food by fewer people and less land (Jain *et al.* 1996).

To face the demands for increasing global food production, plant breeding is adopting new approaches to develop improved cultivars and increase crop yields. The impacts of global climatic changes and unending pathogen evolution on the sustainability of agriculture pose new challenges for breeders and necessitate the adoption of breeding strategies to ensure the release of widely adapted cultivars. New technologies provide valuable assistance to increase selection efficiency through indirect selection for agronomically valuable traits (Landjeva *et al.* 2007). Advances in technologies contribute to crop improvement by increasing the efficiency of generating accurate and unique phenotypes and genotypes in well-characterized environments (Sorrels 2007).

In vitro haploid production is among the technologies that offer great help to plant breeders to increase crop yield by developing true breeding lines. The production of haploid plants (plants with the gametic chromosome number "*n*") or doubled haploid plants (plants or cells that were haploid but have their chromosome number doubled to the normal somatic number "2*n*" via duplication) have long been recognized and researched for their application in plant breeding and other research areas (Kasha *et al.* 2001). The development of true-breeding or homozygous lines is an important tool for breeding purposes. In traditional breeding methods, the development of true-breeding lines requires several generations of backcrossing and self-pollination. By the double haploidy process, immature pollen grains, called microspores are cultured to produce true-breeding plants in one generation.

Therefore, doubled-haploid techniques can reduce the time required to develop a new variety by about three to four years (Kernan & Ferrie 2006). The diploid homozygous pure lines obtained by *in vitro* haploid production can be used to produce new cultivars, more resistant to a wide range of diseases and to be tolerant to different kinds of biotic and abiotic stresses. All these combined features would lead to a significant increase in yield production. Agronomic efficiency boost of cultivated species would imply a vertical raise in food production, avoiding the pressure to enlarge already cultivated areas and decreasing the possibility to use agricultural crops on areas of environmental preservation (Lee 2005). Fewer applications or even elimination of chemical pesticides are the results of obtaining plants tolerant or resistant to a wide range of diseases. In this case, environmental preservation can be accomplished by the reduction in the energy spent in the production and application of pesticides and fertilizers.

Plants originated by double haploid production and adapted to soils with excess or deficit of water, can be also used in previously abandoned rural properties, optimizing areas with cultivated plants, and increasing regional food production without affecting areas under environmental preservation. New genetic combinations are continuously required to meet the challenges of nature such as climatic change, ongoing pathogenic variation, and lack of essential nutrients (Landjeva *et al.* 2007). Information on the degree of genetic variation and diversity changes over time could contribute to the efficient conservation, maintenance and rational utilization of germplasm resources, thus opposing the process of genetic erosion. In this case, double haploid technique can also be used in germplasm banks to fix lines of agronomic interest as a resource in a pre-breeding program. For these reasons, every progress conquered through the double haploid technique contributes direct or indirectly for the reduction of emissions of carbon dioxide once it turns the productive process more efficient under the energy point of view. Integration of advanced agricultural techniques into a conventional breeding program is a way of crop improvement strategy that has the potential to improve the efficiency of traditional plant breeding.

The use of marked-assisted selection (MAS) for improving complex traits, as race-nonspecific rust resistance, is another challenge facing wheat breeders. According to Somers *et al.* (2007)

the implementation of molecular breeding technique requires certain genetics resources, the most important being a high-density genetic map of the crop species as well as access to genetic markers; these are the basic tools in molecular breeding. The usefulness of genetic markers in practical plant breeding relates to their deployment as indirect selection criteria and the potential they offer in making breeding procedures more efficient. Several factors are considered when choosing indirect selection over direct selection in practical plant breeding. For example, when the alleles do not individually exert detectable effects on the expression of the trait, MAS allows breeders to identify the presence of multiple genes/alleles related to a single trait. Also, markers associated with desirable recessive alleles would enable breeders avoid the extra selfing step and progeny testing in backcross introgression approaches. Molecular markers are attractive alternatives when it is expensive or laborious to screen for a specific trait or when assays requires a large number of seeds. They also can provide a significant advantage in identifying traits that can only be screened in certain seasons or geographical locations or to identify traits with low heritability. Since assays can be conducted using seeds or young plants, early detection of individual plants carrying target genes improves selection efficiency (William *et al.* 2007). Efficient molecular markers have been used in breeding programs to facilitate selection of genotypes resistant to the three wheat rust pathogens (Bariana *et al.* 2007; Lagudah *et al.* 2006; Mago *et al.* 2005; Prins *et al.* 2001; Robert *et al.* 1999; Sing 1992; Sing *et al.* 1998). Marker assisted selection is increasingly being adopted by wheat breeding programs in the public and private sectors and the success of its utilization for wheat improvement will depend on the closeness of biotechnologists and the breeders working together.

Wheat improvement also depends on a continued supply of genetic variability and even though some 25,000 cultivars are available, variability from some traits such as resistance to various diseases does not exist in wheat (Fedak 1998). Wild relatives of cultivated wheat are valuable for breeding programs because they can be used to increase wheat gene pool. These species possess many identified agronomical favorable characteristics not readily found in the wheat (Feldman & Sears 1981; Sharma & Gill 1983). Numerous genes of importance have been introduced to wheat from its wild progenitors through wide hybridization and chromosome

manipulation resulting in interchromosomal translocation involving wheat chromosomes and the homologous chromosomes of related species (Jiang *et al.* 2004; McIntosh *et al.* 2003). Most of the species of tribe Triticeae carry wheat leaf rust resistance genes (Jones *et al.* 1995; Stepién *et al.* 2003; Zaharieva *et al.* 2001). *Aegilops tauschii* may be the most useful of the many related species for improvement of wheat and its D genome demonstrates an unparalleled wealth of genetic diversity for several biotic and abiotic stresses (Mujeeb-Kazi & Rajaram 2002). This species have been used as donor of important resistance genes which give both race-specific and race-nonspecific resistance (Cox *et al.* 1994; Dyck & Kerber 1970; Kerber 1987; Rowland & Kerber 1974). Although some of these genes have lost their effectiveness due to the emergence of more virulent forms of *P. triticina*, a number of such genes are still effective in different geographical reasons (McIntosh *et al.* 1995).

Cytogenetic markers as Genomic *In Situ* Hybridization (GISH) has applications in characterization of genomes and chromosomes in hybrid polyploidy, hybrid plants, partial allopolyploids, polyhaploids and recombinant breeding lines, and in the localization, and detection of amount of introgressed alien chromatin. Many leaf rust and stem resistance genes have been introgressed from *Agropyron elongatum* and *A. intermedium* to cultivated wheat and GISH analysis have been used to confirm the sizes of translocations, and reveal the breakpoint in many translocations lines (Raina & Rani 2001). The species *Thinopyrum intermedium* and *Th. ponticum* also have been extensively for hybridization with *Triticum aestivum* and numerous useful genes, particularly for leaf rust and stem rust resistance, have been successfully transferred and confirmed using GISH analysis (Chen *et al.* 1998; Fedak *et al.* 2000; Brasileiro-Vidal *et al.* 2003, 2005).

CONCLUSIONS

Modern wheat varieties have undoubtedly made important contributions toward sustainable agriculture, both indirectly, through the adoption of land saving technologies, and directly through the more efficient use of external inputs and the increased stability of production. In the future, the further diffusion of modern varieties as well as the development of newer generations of them will continue to be important in promoting a more sustainable agriculture. One of the most important contributions of modern varieties is enhanced disease resistance, permitting reductions in the use of harmful pesticides and promoting greater stability of yields. There is every reason to expect that the contribution of modern varieties to productivity growth and sustainability will be maintained in the future (Byerlee 1996).

Development of new wheat varieties has been shown to be a high-return investment, by virtue of the yield and quality gains that have come through improved varieties. The wide range of new technologies in fields such genomics, molecular biology, plant physiology, doubled haploids, cytogenetics and statistical analysis provide an opportunity for wheat breeders to make even greater contributions in the future. It seems likely that the international agricultural research centers have a key role to play in ensuring that the level of access of technology is such that breeding programs in less developed countries are not disadvantaged in this process (Brennan & Martin 2007).

The coming 50 years are likely to be the final period of rapidly expanding, global human environmental impacts. Future agriculture practices will shape, perhaps irreversible, the surface of the Earth, including its species, biogeochemistry and utility to society. Technological advances and current economic forces have both increased food availability and decreased the real costs of agricultural commodities during the past 50 years. But the resulting agricultural practices have incurred costs related to environmental degradation, loss of biodiversity, loss of ecosystem services, emergence of pathogens, and long-term stability of agricultural production. The goal of sustainable agriculture is to maximize the net benefits that society receives form agricultural production of food. This will require increased yield crops yields, increased efficiency of nitrogen, phosphorus and water use, ecologically based management practices and judicious use of pesticides. Advances in the fundamental understanding of agroecology, biogeochemistry and biotechnology that are linked directly to breeding programs can contribute greatly to sustainability. Sustainable agriculture must be a broadly based effort that helps assure equitable, secure, sufficient and stable flows of both food and ecosystem services for the 9,000 million or so people likely to inhabit in Earth (Tilman 2002).

REFERENCES

Abdel Hak T.M, N.A. El-Sherif , A.A. Bassiouny, I.I. Shafik, and Y. El-Duadi. 1980. Control of wheat leaf rust by systemic fungicides. *Proceedings of the Fifty European and Mediterranean Cereal Rusts Conference, Bari, Italy.* pp. 255-266.

Andrade, V.O. 1990. Polvillo estriado o roya amarilla *(Puccinia striiformis* Westend) del trigo en la zona sur de Chile. Instituto de Investigaciones Agropecuárias, Estación Experimental Carillanca, Boletín Técnico No. 164, Temuco.

Antonelli, E.F. 2000. La roya negra del tallo *(Puccinia graminis* f. sp. *tritici*). Una ilustre ausente de los campos de trigo. Por cuánto tiempo más? (Grafos:Necochea, Argentina).

Bariana, H.S.; H. Miah, G. N. Brown; N. Willey. 2007. Molecular mapping of durable rust resistance in wheat and its implication in breeeding. In: H. T. Buck, J. E. Nisi and N. Salomón (eds) Wheat Production in Stressed Environments. *Proceeding of the 7th International Wheat Conference, Mar del Plata, Argentina – Developments in Plant Breeding.* 12: 723-728.

Biffen, R.H. 1905. Mendel's laws of inheritance and wheat breeding. *J Agri Sci.* 1: 4-48.

Bockus, W.W., J.A. Appel, R.L. Bowden, Fritz, A.K., B.S. Gill, T.J. Martin, R.G. Sears, D.L. Seifers, G.L. Brown-Guedira, and M.G. Eversmeyer. 2001. Success histories: Breeding for Wheat Disease Resistance in Kansas. *Plant Disease.* 85(5): 453-461.

Brasileiro-Vidal, A.C., A. Cuadrado, S.P. Brammer, M.B. Iseppon and M. Guerra. 2005. Molecular cytogenetic characterization of parental in the partial amphidiploid *Triticum aestivum* x *Thinopyrum ponticum. Genet Mol Biol.* 28(1): 308-313.

Brasileiro-Vidal, A.C., A. Cuadrado, S.P. Brammer, A.C. Zanatta, A.M. Prestes, M.I.B. Fernandes, and M. Guerra. 2003. Chromosome characterization in *Thinopyrum ponticum* (Triticeae - Poaceae) using in situ hybridization with different DNA sequences. *Genet Mol Biol.* 26(4): 505-510.

Brennan, J.P and P.J. Martin. 2007. Returns to investment in new breeding technologies. *Euphytica.* 157: 337-349.

Brennan, J.P and G.M. Murray. 1988. Australian wheat diseases – assessing their economic importance. *Agri Sci New Series* 1: 26-25.

Byerlee, D. and P. Moya. 1993. Impacts of international wheat breeding research in the developing world, 1966-1990. International Maize and Wheat Improvement Center (CIMMYT), Mexico, D.F., Mexico.

Byerlee, D. and G. Traxler. 1995. National and international wheat improvement research in the post-Green Revolution period: Evolution and impacts. *American J Agri Econ.* 77: 268-278.

Byerlee, D.1996. Modern varieties, productivity and sustainability: Recent experience and emerging challenges. *World Develop.* 24(4): 697-718.

Caldwell, R.M. 1968. Breeding for general and/or specific plant disease resistance. In: K.W. Finlay and K.W. Shepherd, eds. Proceedings of 3rd. International Wheat Genetic Symposium. Australian Academy of Sciences, Canberra. pp. 236-272.

Chen, Q., R.L. Conner, A. Laroche, and J.B. Thomas. 1998. Genome analyses of *Thinopyrum intermedium* and *Thinopyrum ponticum* using genomic *in situ* hybridization. *Genome.* 41: 580-586.

Cox, T.S., W.J. Raupp and B.S. Gill. 1994. Leaf rust-resistance genes *Lr41*, *Lr42* and *Lr43* transferred from *Triticum tauschii* to common wheat. *Crop Sci.* 34: 339-343.

Dalrymple, D.G. 1985. The development and adoption of high-yielding varieties of wheat and rice in developing countries. *American J Agri Econ.* 67: 1067-1073.

Dixon, J., L. Nalley, P. Kosina, R. La Rovere , J. Hellin and P. Aquino. 2006. Adoption and economic impact of improved wheat varieties in the developing world. *J Agri Sci.* 144: 489-502.

Duveiller, E., R.P. Singh, and J.M. Nicol. 2007. The challenges of maintaining wheat productivity: pests, diseases, and potential epidemics. *Euphytica.* 157:417-430.

Dyck, P.L. and E.R. Kerber. 1970.Inheritance in hexaploid wheat of adult plant leaf rust resistance derived from *Aegilops squarrosa*. *Canadian J Genet and Cytol.* 12: 175-180.

Expert Panel on Stem Rust Outbreak in Eastern Africa (2005). Sounding the alarm on global stem rust: An assessment of race Ug99 in Kenya and Ethiopia and the potential for impact in neighboring regions and beyond. CIMMYT, Mexico, D.F. Available online at *http://www.cimmyt.org/english/wps/news/2005/aug/pdf/Expert_Panel_Report.pdf* (Accessed December 6, 2007).

FAO (Food and Agriculture Organization of the United Nations). 2006. *FAOSTAT Production Statistics.* Rome, Italy:FAO.

Fedak, G. 1998. Procedures for transferring agronomic traits from alien species to crop plants. *Proceedings of 9th International Wheat Genetics Symposium.* pp. 1-7.

Fedak, G., Q. Chen, R.L. Conner, A. Laroche, R. Petroski, and K.W. Armstrong, 2000. Characterization of wheat-*Thinopyrum* partial amphiploids by meiotic analysis and genomic *in situ* hybridization. *Genome.* 43: 712-719.

Feldman, M. and E.R. Sears. 1981. The wild gene resources of wheat. *Scientific American.* 224: 102-112.

Flor, H.H. 1956. The complementary genic systems in flax and flax rust. *Advances in Genetics.* 8: 29-54.

Fresco, L.O. and W.O. Baudoin. 2002. Food and nutrition security towards human security. In: *Proceedings of the International Conference on Vegetables, (ICV-2002),* 11-14 November 2002, Bangalore, India. Bangalore, Dr Prem Nath Agricultural Science Foundation.

Germán, S., A. Barcellos, M. Chaves, M. Kohli, P. Campos, and L. Viedma. 2007. The situation of common wheat rusts in the Southern Cone of América and perspectives for control. *Australian J Agri Res.* 58: 620-630.

Green, GJ and A.B. Campbell. 1979. Wheat cultivars resistant to Puccinia graminis tritici in western Canada, their development, performance and economic value. *Can J Plant Pathol.* 1: 3-11.

Hussain, M., S.F. Hassan and M.A.S. Kirmani. 1980. Virulences of *Puccinia recondita* Rob. ex Desm. f.sp. *tritici* in Pakistan during 1978 and 1979. *Proceedings of the Fifth European and Mediterranean Cereal Rusts Conference, Bari, Italy.* pp. 179-184.

Jain, S.M., S.K. Sopory and R.E. Veilleux, 1996. *In vitro* haploid production in higher plants. Volume 1: Fundamental Aspects and Methods. Kluwer Academic Publishers, Dordrecht, Boston & London.

Jiang, J., B. Friebe, and B.S. Gill. 1994. Recent advances in alien gene transfer in wheat. *Euphytica.* 72:199-212.

Jones, S.S., T.D. Murray and R.E. Allen. 1995. Use of alien genes for the development of disease resistance in wheat. *Ann Rev Phytopathol.* 33: 429-443.

Joshi, L.M. 1976. Recent contributions towards epidemiology of wheat rusts in India. *Indian Phytopathol.* 29:1-16.

Kasha, K.J., E. Simion , R. Oro, Q.A. Yao, T.C. Hu, A.R. Carlson. 2001. An improved *in vitro* technique for isolated microspore culture of barley. *Euphytica.* 120 (3): 379-385.

Keed, B.R. and NH. White. 1971. Quantitative effects of leaf and stem rusts on yield and quality of wheat. *Australian J Exp Agri Animal Husband.* 11: 550-555.

Kerber, E.R. 1987. Resistance to leaf rust in hexaploid wheat: *Lr32* a third gene derived from *Triticum tauschii. Crop Sci.* 27: 204-206.

Kernan, Z. and M.R. Ferrie 2005. Microspore embryogenesis and the development of a double haploid protocol for cow cockle (*Saponaria vaccaria*). *Plant Cell Reports.* 25(4): 274-280.

Lagudah, E.S., H. McFadden, R.P. Singh, J. Huerta-Espino, H.S. Bariana, and W. Spielmeyer. 2006. Molecular genetic characterization og the *Lr34/Yr18* slow rusting resistance gene region in wheat. *Theor and Appli Genet.* 114: 21-30.

Landjeva, S., V. Korzun, A. Börner. 2007. Molecular markers: actual and potential contributions to wheat genome characterization and breeding. *Euphytica.* 156 (3): 271-296.

Lee, D.R. 2005. Agricultural sustainability and technology adoption: issues and policies for developing countries. *American J Agri Econ.* 87 (5): 1325-1334.

Lipsey, R.G. and A. Chrystal. 2007. *Economics.* 10th ed. Oxford (UK): Oxford University Press (Academic).

Mago, R., H. S. Bariana, I.S. Dundas, W. Spielmeyer, G. L. Lawrence, A.J. Prior and J.G. Ellis. 2005. Development of PCR markers for selection of wheat stem rust resistance genes *Sr24* and *Sr26* in diverse wheat germplasm. *Theor and Appl Genet.* 111: 496-504.

Marasas, C.N., M. Samale, and R.P. Singh. 2003. The economic impact of productivity maintenance research: breeding for leaf rust resistance in modern wheat. *Agri Econ.* 29: 253-263.

McIntosh, R.A., C.R. Wellings and R.F. Park. 1995. *Wheat rusts: An atlas of resistance genes.* CSIRO. East Melbourne, Australia.

McIntosh, R.A., Y. Yamazaki, K.M. Devos, J. Dubkowsky, W.J. Rogers, and R. Appels. 2003. Catalogue of gene symbols for wheat. In: N.E. Pogna, M. Romano, E.A. Pogna and G. Galterio (Eds) *Proceedings of the 10th International Wheat Genetics Symposium. Pasteum, Italy.* 4: 1-34.

Mujeeb-Kazi, A. and S. Rajaram. 2002. Transferring alien genes from related species and genera for wheat improvement. In: *Bread Wheat Improvement and Production FAO.* pp.199-215.

Oerke, E.C. 2006. Crop losses to pests. J Agril Sci. 144(1): 31-43.

Priestley, R.H. and R.A. Bayles. 1988. The contribution and value of resistance cultivars to disease control in cereals. In: B.C. Clifford and E. Lesser (eds) *Control of plant diseases: Costs and benefits.* Blackwell Scientific Publications: Oxford. pp. 53-65.

Prins, R., J.Z. Groenewald, G.F. Marais, J.W. Snape and R.M:D. Koebner. 2001. AFLP and STS tagging of *Lr19*, a gene conferring resistance to leaf rust in wheat. *Theor Appl Gen.* 103: 618-624.

Raina, S.N. and V. Rani. 2001. GISH Technology in plant genome research. *Methods in Cell Sci.* 23: 83-104.

Rajaram, S. 2001. Prospects and promise of wheat breeding in the 21st century. *Euphytica.* 119: 3-15.

Rees, R.G. and G.J. Platz. 1975. Control of wheat leaf rust with 4-n-butyl-1,2,4-triazole. *Australian J Exp Agri Animal Husband.* 15: 276-280.

Reynolds, M.P. and N.E. Borlaug. 2006. Impacts of breeding on international collaborative wheat improvement. *J Agri Sci.* 144: 3-17.

Robert, O., C. Abelard, and F. Dedryver. 1999. Identification of molecular markers for detection of the yellow rust resistance gene *Yr17* in wheat. *Molecular Breeding* 5: 167-175.

Roelfs, A.P. 1978. Estimated losses caused by rust in small grain cereals in the United States – 1918-1976. Miscellaneous Publication 1363. United States Department of Agriculture:Washington DC.

Roelfs, A.P.; R.P. Singh and E.E. Saari. 1992. Rust diseases of wheat: Concepts and methods of disease management. CIMMYT:Mexico, D.F.

Rosengrant, M.W. and S.A. Cline. 2003. Global food security: challenges and policies. *Science.* 302: 1917-1919.

Rowland, G.G. and E.R. Kerber. 1974. Telocentric mapping in hexaploid wheat of genes for leaf rust resistance and other characters derived from *Aegilops squarrosa. Can J Genet Cytol.* 16: 137-144.

Saari, E.E. and J.M. Prescott. 1985. World distribution in relation to economic losses. In: A.P. Roelfs and W.R. Bushnell (eds.), *The Cereal Rusts Volume II: Diseases, Distribution, Epidemiology and Control.* Academic Press: London and Orlando. pp. 259-258.

Samale, M., R.P. Singh, K. Sayre, S. Pingali, S. Rajaram, and H.J. Dubin. 1998. Estimating the economic impact of breeding nospecific resistance to leaf rust in modern bread wheats. *Plant Disease.* 82: 1055-1061.

Samborski, D.J. 1985. Wheat leaf rust. In: A.P. Roelfs and W.R. Bushnell (eds.), *The Cereal Rusts Volume II: Diseases, Distribution, Epidemiology and Control.* Academic Press: London and Orlando. pp. 39-59.

Sharma, H.C. and B.S. Gill. 1983. Current status of wide hybridization in wheat. *Euphytica.* 32: 17-31.

Sing, R.P. 1992. Genetic association of leaf rust resistance gene *Lr34* with adult plant resistance to stripe rust and bread wheat. *Phytopathol.* 82: 835-838.

Sing, R.P., A. Mujeeb-Kazi, and J. Huerta-Espino. 1998. *Lr46*: a gene conferring slow-rusting resistance to larf rust in wheat. *Phytopathol.* 88: 890-894.

Singh, R.P. and J. Huerta-Spino. 2001. Global monitoring of wheat rusts, and assessment of genetic diversity and vulnerability of popular cultivars. Research Highlights of the CIMMYT wheat program, 1999-2000. CIMMYT: Mexico, D.F.

Singh, R.P., D.P. Hodson, Y. Jin, J. Huerta-Spino, M.G. Kinyua, R. Wanyera, P. Njau, and R. Ward. 2006. Current status, likely migration and strategies to mitigate the threat to wheat production from race Ug99 (TTKS) of stem rust pathogen. *CAB Reviews* 1. 54: 1-13.

Singh, R.P., H.M. William, J. Huerta-Spino, and G. Rosewarne. 2004. Wheat rust in Asia: Meeting the changes with old and new technologies. In: Proceedings of the 4th International Crop Science Congress, Brisbane, Australia. Available on line at : *http://www.cropscience.org.au/iscs2004/symposia/3/7/141_singhrp.htm* (Accessed and verified September 13, 2005).

Somers, D.J., C. Mccartney, R. Depauw, J. Thomas, S. Fox, G. Fedak, G. Humphreys, J. Gilbert and B. Mccallum. 2007. Molecular breeding for multiple pest resistance in wheat. In: H. T. Buck, J. E. Nisi and N. Salomón (Eds) *Wheat Production in Stressed Environments. Proceeding of the 7th International Wheat Conference, Mar del Plata, Argentina – Developments in Plant Breeding.* 12: 667-676.

Sorrells, M. 2007.Application of new knowledge, technologies, and strategies to wheat improvement. *Euphytica.* 157: 299-306.

Stakman, E.C., D.M. Stwart and W.Q. Loegerin. 1962. Identification of physiologic races of Puccinia graminis var. tritici. U.S. Department of Agriculture, Agriculture Research Service. E-617 (rev.).

Stepién, L., L. Golka and J. Chelkowski. 2003. Leaf rust resistance genes of wheat: identification in cultivars and resistance sources. *J Appl Genet.* 44: 139-149.

Tilman, D., K.G. Cassman, P.A. Matson, R. Naylor, and S. Polasky. 2002. Agricultural sustainability and intensive production practices. *Nature.* 418: 671-677.

Trethowan, R.M., M. Reynolds, K. Sayre and I. Ortiz-Monasterio. 2005. Adapting wheat cultivars to resource conserving farming practices and human nutritional needs. *Annal App Biol.* 146: 405-413.

Vanderplank, J.E. 1963. *Plant Diseases: Epidemics an control.* Academic Press:New York. pp. 5-52.

Wellings, C.R, P.T.W. Wong and G.M. Murray. 1985. Use of multiple regression to examine the effect of leaf rust and yellow spot on

yield of wheat in northern New South Wales. *Australasian Plant Pathol.* 39: 316-325.

Wellings, C.R. and N.H. Luig. 1984. Wheat rusts, the old and the new. *Australian Institute of Agricultural Science, Occasional Publication.* 15: 5-15.

Wiese, M.V. 1977. *Compendium of wheat diseases.* American Phytopathology Society:St. Paul, Minnesota, USA.

William, H.M., R.Trethowan and E.M. Crosby-Galvan. 2007. Wheat breeding assisted by markers: CIMMYT's experience. *Euphytica.* 157: 307-319.

Zaharieva, M., P. Monneveux, M. Henry, R. Rioval, and J. Valkoun. 2001. Evaluation of a collection of wild wheat relative *Aegilops geniculata* Roth and identification of potential sources for useful traits. *Euphytica.* 119: 33-38.