17. Screening for stem rust resistance in East Africa

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Abstract

The East Africa program of the Borlaug Global Rust Initiative (BGRI) was launched to reduce the scale and scope of wheat stem rust epidemics in Kenya and Ethiopia, and to mitigate the global threat of virulent and dangerous rust races originating from this region. Since the launch in 2005, the screening facilities in Kenya and Ethiopia have helped to determine the extent of the world's vulnerability to stem rust race Ug99 and its variants, identify diverse sources of resistance including adult plant resistance based on minor genes, and catalyze a comprehensive global response, leading to expanded awareness, expanded research and breeding activities, and resource mobilization. This paper reviews the role and achievements of the eastern African screening facilities along with the opportunities and challenges faced by the facilities during the ongoing global response to the emergence of Ug99 and its variants.

Keywords

wheat, *Puccinia graminis tritici*, screening, facilities, Ug99

Introduction

Cereal rusts are among the world's most destructive plant diseases and can cause substantial yield losses or even destroy entire cereal crops. In addition, rust pathogens continue to pose high bio-security risks because they can spread quickly over large distances, easily adapt to the new areas and reach epidemic levels in a short period of time. The rust pathogens are hard to eradicate once introduced because of the continuous and rapid evolution of new races through, mutation, recombination (asexual, or sexual on the alternate host) and selection. Ample examples could be cited on the evolution of new races and corresponding loss of race-specific resistance genes soon after their deployment (a cycle generally referred to as boom-and-bust). Deployment of a single resistance gene on a large scale eventually leads to the selection and increased frequency of new, or previously rare, virulent races that may be a prelude to epidemics.

Environments, such as the east African highlands, further aggravate the problem as these 'hot-spots' enable large populations of rust pathogens to persist year round, contributing to speedy evolution and spread of new physiological races. The discovery of stem rust (caused by *Puccinia graminis* f. sp. *tritici*) race Ug99 in Uganda in 1998 (Pretorius et al. 2000) and its spread/establishment in Kenya and Ethiopia by 2003, Sudan and Yemen in 2006, and more recently in Iran in 2007, supplemented by two independent Ug99 mutations detected in Kenya with added virulence for gene *Sr24* or *Sr36* in 2006 and 2007, respectively, is a classical example of swift pathogen migration and evolution, and the danger it poses on global wheat production. Based on the areas planted to known varieties, pedigrees, and corresponding disease ratings to Ug99 from field screening in Kenya between 2005 and 2006, such variants pose an increased threat to the majority of cultivars grown on at least 90% of the area in the potential risk zones (Singh et al. 2006). It was estimated that the wheat area under risk to Ug99 is around 50 million hectares, which translates to about 25% of world's wheat area (Joshi et al. 2008).

The East Africa program of the Borlaug Global Rust Initiative (BGRI) was recently launched to reduce the scale and scope of stem rust epidemics in Kenya and Ethiopia, and to improve the likelihood that new virulent and dangerous races originating in this region are confined to east Africa. The East African component of the program was therefore designed to also monitor further migration of Ug99 and its variants, facilitate field screening of international wheat germplasm, identify new sources of resistance and understand the genetic basis of resistance (in particular, the durable types), carry out a targeted breeding program to incorporate resistance genes into germplasm of interest, and to enhance the capacity of national programs in breeding for rust resistance.

This paper reports on the operations of screening facilities in Kenya and Ethiopia, and discusses the opportunities and challenges of managing them.

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East African screening facilities and operational logistics

Screening locations

The facilities operate from two sites – Njoro Plant Breeding Research Center (NPBRC), Kenya Agricultural Research Institute (KARI); and Debra Zeit Research Center (DZRC), Ethiopian Institute of Agricultural Research (EIAR).

The KARI NPBRC is 200 Km west of Nairobi in Nakuru district, Rift Valley province. The center is located 2,185m above sea level at latitude $0^0$20'S, longitude $35^0$56'E. The average rainfall is 933 mm per annum with average daily minimum and maximum temperatures of 10^0 (night) and 23^0 (day), respectively. The station screening activities are mainly for bread wheat (limited durums and barley) and are coordinated across two seasons ('Main' = June to October, and 'Off-season' = November to April). Twelve hectares of irrigated land has been dedicated to field screening (4 ha available per season to accommodate a 3-season rotation) involving more than 20,000 entries per season. The germplasm evaluated includes both spring wheat and winter wheat representing advanced breeding materials, landraces, local cultivars, mapping populations and historical germplasm. The facilities also cater for shuttle breeding by CIMMYT, ICARDA, and other NARS and organizations.

The EIAR DZRC is based 40 Km south-east of Addis Ababa. The center is at an elevation of 1,850 m above sea level at latitude of $8^0$44'N, longitude 38^0 85'E. The average rainfall is 851 mm annually with average daily minimum and maximum temperatures of 9^0 (night) and 24^0 (noon), respectively. DZRC's screening activities are also co-ordinated over 12 ha of land (6 ha/rotation) during two seasons ('Main' = June to November, and 'Off-season' = January to April). The station co-ordinates screening of international wheat materials and shuttle breeding (primarily durum wheat) and can handle more than 15,000 entries per season. In addition, there are facilities at Ambo Plant Protection Research Center which focuses on rust surveillance and race analysis; and Kulumsa Research Center with emphases on wheat breeding, rust screening of bread wheat and seed multiplication.

Screening methodology

For phenotyping, the spring wheat materials are planted as double 1-m-rows. Winter wheat is vernalized for 6-8 weeks at 4^0C in vernalization chambers before transplanting to the field as hill plots. To facilitate inoculum increase and uniform spread within the nursery, clumps of selected spreaders (mixture of cultivars susceptible to Ug99 and variants) are planted adjacent to entries. The spreader rows are inoculated either by dusting them with a mixture of talcum powder and urediniospores, or by syringe inoculations with water suspensions, as outlined in McIntosh et al. (1995). In 2008, the predominant field races were typed as TTKSK (Ug99) + TTKST (Ug99+*Sr24*) in Kenya, and TTKSK in Ethiopia. Infection responses are categorized into four discrete classes: viz. resistant (R), moderately resistant (MR), moderately susceptible (MS) and susceptible (S). Infection responses overlapping between any two categories are denoted using a dash (e.g. MR-MS to represent overlapping between MR and MS responses). Stem rust severity is assessed using the modified Cobb scale (Peterson et al. 1948). Entries are evaluated for infection response and stem rust severity 2-3 times between heading and maturity. In addition, notes are taken (although not routinely) on growth habit, stripe rust and leaf rust response. The rust data include responses to natural stripe rust and leaf rust infections occurring in the Njoro plots.

Operational logistics

Staff of KARI, EIAR and CIMMYT work very closely with national and international collaborators, stakeholders and donors. Collaborators liaise with the National focal points (KARI and EIAR) via the International focal point (CIMMYT-Nairobi) three months in advance of each growing season. Both facilities cater for two cycles per year so planting dates are crucial and it is imperative that deadlines be achieved. If material does not arrive by the specified deadlines, it is held over until the following season. All seed-lots imported into Kenya and Ethiopia require valid import permits and must meet phytosanitary requirements. Import permits are organized and sent to collaborators on request. An ordinary seed import permit normally takes 2-5 days to be granted and is valid for six months after issue. Instructions outlining importation procedures must be followed strictly to ensure successful importation. On customs and quarantine clearance, the material is taken to the research testing sites of NPBRC and DZRC, where it may be subjected to further plant health checks to prevent the possibility of exotic pests and diseases from outside east Africa. The material will be planted only after final clearances.

In 2009, all germplasm will be exchanged under a standard material transfer agreement (SMTA) for the purpose of research and breeding. KARI and EIAR will hold the germplasm in trust for the international community in accordance with the terms of the SMTA of the International Treaty for Plant Genetic Resources for Food and Agriculture. For commercialization purposes and other potential uses, germplasm exchange can take place on a case-by-case basis, with mutually

agreed arrangements between the collaborators. The information generated will be open-access unless there is a special MTA with the supplier. Kenyan and Ethiopian NARS will have direct access to all materials and information for research and breeding purposes because of their contribution/services to the screening facilities.

Almost all developing country programs and International Agricultural Research Centers are currently exempt from the payment of screening fees. However, a fee may be applicable to some industrialized country programs and private companies. For further information on the operations of rust screening facilities in east Africa, visit www.globalrust.org

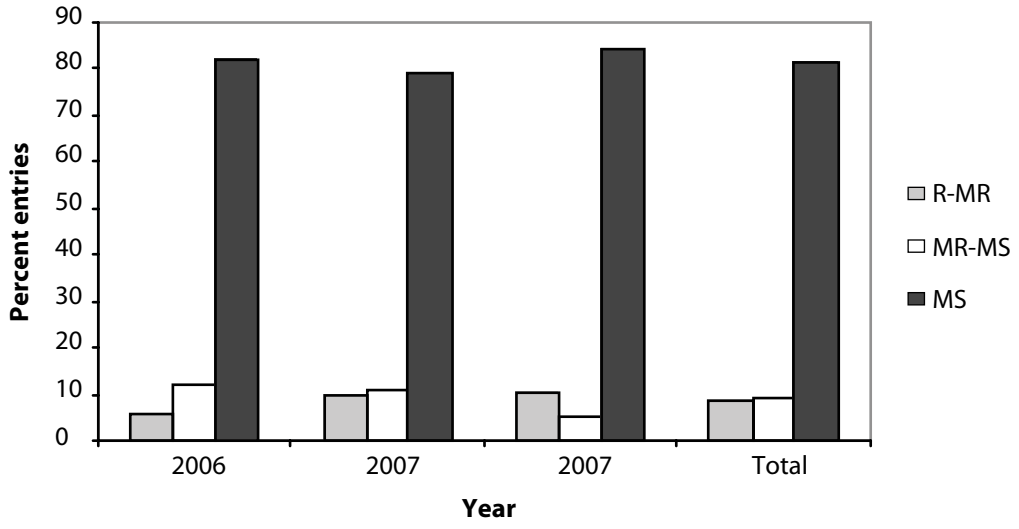
Achievements

Wheat-producing nations throughout the world (more than 25 collaborators from 20 countries) have participated in stem rust response tests of wheat (over 80,000 research plots) in both main and off-season nurseries in Kenya and Ethiopia since 2005. The resistance status of these lines is available and has been disseminated to collaborators. There has been a high demand for international screening over the last three years, and screening requests have almost tripled since 2005.

In 2008, more than 20,000 lines from 20 countries were screened in Kenya. Rust infection was excellent and disease pressure was very high. The responses of controls/differentials showed virulence for genes *Sr31* and *Sr24* in the screening nursery, indicating the likely presence of Ug99 and its variant, Ug99+*Sr24*. *Sr36* was partially effective probably because of a low frequency of *Sr36*-virulence in the pathogen population. A low frequency of resistant entries was a common feature among wheat materials from many countries with more than 80% of screened germplasm susceptible, a trend not much different from the previous two years (Fig. 1). Among the resistant materials (classified in the R-MR and lower MR-MS categories), the highest frequencies of resistant entries were in Canadian germplasm (30%), followed by CIMMYT (25%), ICARDA (13%), USDA (9%), Australia (5%), India (5%), Egypt (4%), Uruguay (3%), Argentina (3%), and all others 3% (Fig. 2). Lines with notable resistance included *Sr25* derivatives, several tall Giza lines from Egypt, derivatives of the Chinese wheat cultivar Shanghai#7, Canadian materials (Thatcher background plus leaf rust resistance gene *Lr34*), some ICARDA and CIMMYT lines, and several Egyptian and CIMMYT durums. Varied responses of materials with *Sr2* were also evident.

Good progress was made in identifying diverse sources of resistance to Ug99 and its variants in international germplasm including minor gene adult plant resistance (APR), which in cereal rust systems has a reputation of durability. More than 300 germplasm sets in the form of three stem rust resistance screening nurseries (1st SRRSN, 2nd SRRSN and 3rd SRRSN) were distributed, or are under the process of being distributed. A high proportion of lines (44%) in these three nurseries have shown good to moderate levels of resistance in at least two seasons of evaluation in Kenya. Some promising lines with very good agronomic traits and resistance to Ug99 and its variants have been

Fig. 1 Comparative field response (R-MR, up to 20% disease severity with small uredinia; MR-MS, up to 40% disease severity with medium uredinia; MS-S, 50-100% disease severity with medium to large uredinia) of germplasm screened at KARI during 2006-2008



identified in both the Ethiopian and Kenyan breeding programs, and are under further evaluation or testing for use in breeding programs worldwide, or for direct release and registration in Kenya and Ethiopia.

Opportunities and Challenges

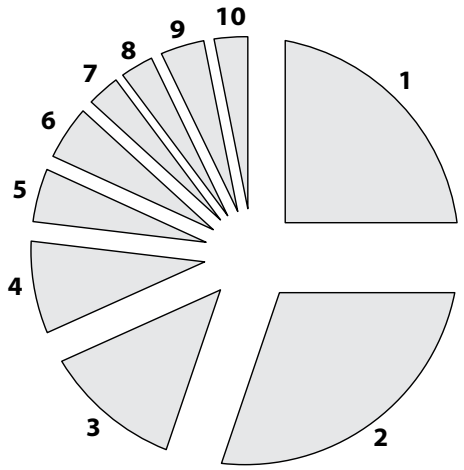
The screening work in east Africa has confirmed the vulnerability of the global wheat industry to race Ug99 (and its variants), and has assessed the effectiveness of known stem rust resistance genes against the Ug99 lineage. East Africa remains the only region where, currently, field screening for responses to the Ug99 lineage can be conducted with a reasonable capacity and with international support. However, fully operational 'Critical Facilities in East Africa' require further investments in field, irrigation, greenhouse, and laboratory facilities and equipment, as well as operational support, for mission-dedicated teams of national and international scientists. Currently, the facilities are being supported by the BGRI/DRRW Project, but long-term funding needs to be secured for sustainability and commitment to a global effort for minimizing yield losses by breeding wheat cultivars resistant to Ug99. Facilities for screening at the hot-spot locations in Kenya and Ethiopia should be expanded and strengthened to cater for future international needs. Protection of the world wheat crop through development of varieties durably resistant to Ug99 cannot be achieved without the continued expansion of the recently initiated collaborative research conducted in east Africa. At the same time, international and regional co-operation should be enhanced to facilitate human resource development in testing, surveillance and pathology, breeding, information sharing, and data management and access.

The objectives of the BGRI/DRRW Project and collaborations with NARS public sector elements are, in principle, not subject to screening fees. However, we have developed a fee-for-service model for private companies and the industrialized countries for screening germplasm. In return, this will support and sustain the activities of the facilities and will provide quality assurance of the data generated. This fee-for-service will be implemented from main season 2009.

Kenya and Ethiopia are free from certain diseases and the frequent importation of seed from many locations poses a risk of exotic pests/diseases that may accompany seed imported from outside east Africa. Because a breach in quarantine could place the entire testing and screening program in jeopardy, it is important that a seed health/ containment facility be established at each station, in addition to normal national phytosanitary and quarantine protocols. Procedures and policies for such laboratories are currently being discussed.

If current activities can be sustained, with all opportunities exploited and challenges met, the critical facilities in Kenya and Ethiopia will be high caliber components of an integrated world effort to minimize the destabilizing effects of rusts on world wheat production and food security.

Fig. 2 Percentages of resistant (R-MR and MR-MS) spring wheat entries from different countries/institutions during 2008 screening at Njoro (1, CIMMYT; 2, Canada; 3, ICARDA; 4, USDA; 5, Australia; 6, India; 7, Uruguay; 8, Argentina; 9, Egypt; 10, Others)



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