DETECTION OF VIRULENCES AND EVALUATION OF WHEAT LINES (*Triticum* spp.) FOR RESISTANT TO STRIPE , LEAF AND STEM RUST (*Puccinia* spp.) IN CENTRAL AND SOUTH-EAST ETHIOPIA

MSC THESIS

TAMIRAT NEGASH GURE

HAWASSA UNIVERSITY

COLLEGE OF AGRICULTURE

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TAMIRAT NEGASH GURE

MAJOR ADVISOR: ALEMAYEHU CHALA (PhD)

CO-ADVISOR: WULETAW TADESSE (PhD)

CO-ADVISOR: EVANS LAGUDAH (PhD)

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IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

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(SPECIALIZATION: CROP PROTECTION)

FEBRUARY, 2017

Approval sheet-I

This is to certify that the thesis entitled "DETECTION OF VIRULENCES AND EVALUATION OF WHEAT LINES (Triticum spp.) FOR RESISTANCE TO STRIPE, LEAF AND STEM RUST (*Puccinia* spp.) IN CENTRAL AND SOUTH-EAST ETHIOPIA" submitted in partial fulfillment of the requirements for the degree of **Master's** with specialization in Crop protection, the graduate program of the department/school of plant and horticultural sciences, and has been carried out by Tamirat Negash_ID .NO SGS/Crop/047/07 under my/our supervision. Therefore I/We recommend that the student has fulfilled the requirements and hence herby can submit the thesis to the department.

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DEDICATION

In memory of my father, Negash Gure whom I lost untimely under rock while am waiting him but always dwells in my heart and spirit forever in his soul.

LIST OF ABBREVIATIONS

ABC	Approximate Bayesian Computation
CIMMYT	International Maize and wheat improvement Center
CI	Coefficient of infection
CSA	Central Statistical Agency
DAP	Die Ammonium Phosphate
DZARC	Debrezeit Agricultural Research Center
EC	Emulsified concentrate
EIAR	Ethiopian institute of agricultural research
G.C	Gregorian Calendar
GIS	Geographic Information Systems
ICARDA	International Centre for Agricultural Research in Dry Areas
IT	Infection Type
KARC	Kulumsa Agricultural Research Center
m.a.s.l	Metter above sea level
MH	Maleic Hydrazide
mm	Millimeter
SARC	Sinana Agricultural Research Center
USA	United States of America
WANA	West Asia and North Africa
WP	Wettable Powder

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TAMIRAT NEGASH GURE B.SC. IN CROP PROTECTION

ALEMAYEHU CHALA (PH.D), MAJOR ADVISOR

WULETAW TADESSE (PH.D), CO-ADVISOR

EVANS LAGUDAH (PH.D), CO-ADVISOR

Abstract

Wheat rusts caused by *Puccinia* spp. are among the major biotic constraints of wheat production all over the world, including in Ethiopia. Nowadays different virulent races of stem, yellow and also leaf rust have evolved and threaten wheat production worldwide across all the wheat belt, among which Ethiopia is the most vulnerable. In view of the above facts, the present investigation was carried out to detect the prevailing virulent races, to identify resistance wheat lines and resistance genes to triple rusts in central and south eastern parts of the country. An inventory of 93 wheat lines and checks was made for triple rusts resistance under field conditions of Sinana and Debrezeit. Besides, 409 wheat lines including checks were tested for triple rust resistance at field conditions of Kulumsa Agricultural Research Center in 2015. The experiments were laid out in augmented design. Each plot consisted of two rows of 2-m long with 0.2 m between rows. Leaf, stem and yellow rust severity varied among wheat lines. Wheat lines also varied in their seedling infection types against races and isolates of triple rust in green house. The terminal severity and infection types varied across locations and wheat lines both at field and greenhouse conditions. The terminal severity for yellow rust ranged from 0 to 90S at Sinana and 0 to 40S at Kulumsa field conditions. The terminal severity for stem rust varied from 0 to 90S at Kulumsa and it was as high as 60S on the susceptible cultivar Kekeba at Debrezeit. The terminal severity of leaf rusts varied from 0 to 80S at Debrezeit. Of the 409 wheat lines tested 99.3%, 80.2% and 99. % were resistant to moderately resistant at field conditions of Kulumsa to yellow rust, stem rust and leaf rust, respectively. At Sinana 70.8% and 92.5% of wheat lines tested exhibited resistance to yellow rust and stem rust, respectively, with coefficient of infection ranging from 0 to 30. At Debrezeit 43% and 51% of wheat lines were resistant and moderately resistant to stem and leaf rust, respectively. Wheat lines Sr 50+Sr 45 # 35, Sr 45/Cs #20, Sr 45/Cs #21, Sr 45/Cs #25, Sr 45+Sr 2/Cs #28, Sr 45+Sr 2/Cs #29, Sr 45+Sr 2/Cs# 20, Sr 45+Sr 2/Cs# 33, Sr 45+Sr 2/Cs# 32, Thatcher+Lr 34, Westonia Sr 50+ Sr 26, Westonia Sr 24+ Sr 50 and Pavon Sr 24+ SR 26+Sr 31, were consistently resistant to triple rusts under field conditions across locations. However, the only wheat line resistant to triple rust both at field and seedling tests in green house was Pavon Sr 24+ SR 26+Sr 31, and hence it could be exploited in wheat improvement programs.

Key words: *Infection type, Coefficient of infection, Resistant gene, Severity*

1. INTRODUCTION

The world population was 7.349 billion as of July 1, 2015 according to the medium fertility estimate by the United Nations Department of Economic and Social Affairs, Population Division and population in the world is currently growing at an annual rate of around 1.13%**.** The average population change is currently estimated at around 80 million per year. The rising continent, Africa also has increasing population in the world having the population of about 1.116 billion (Anonymous, 2015a). Ethiopia is second ranking country in Africa with its population of over 90 million (Anonymous, 2015b). The great majority of Ethiopian-population (85%) lives in rural areas, where agriculture is the major stake of livelihood activities. The ever increasing population needs to have increased food source but the only way of increasing productivity is through intensification because the land couldn't have an infinite space for extension. In order to feed the ever increasing population we have to increase wheat production at the rate of 1.6% which can be achieved by developing high yielding varieties having a good tolerance level for biotic and a-biotic stresses (Khan *et al*., 2013).

The most common species of wheat grown are *Triticum aestivum* L. (common wheat) and *Triticum turgidum var. durum* L. (durum wheat). Common wheat accounts for 95% of the total wheat consumed worldwide (Randhawa *et al*., 2013). It is also major crop in Ethiopia that is central to achieving development in agriculture. Ethiopia is the second largest wheat producer in sub-Saharan Africa, after South Africa (Abu Tefera & Teddy Tefera, 2013). Most wheat production in Ethiopia comes from small holder farmers. Wheat is mainly grown in the central and south-eastern highlands during the main (Meher) rainy season (June to September) and harvested in October-November. It is the third most important cereal crop after teff (*Eragrostis tef*) and maize (*Zea mays*) in area coverage and production in Ethiopia. On average, from 2004-2009, wheat was grown on 1.51 million hectares of land, and yielded 2.29 million metric tons of grain yield per year (Teklay Abebe *et al*., 2013). But, in 2015/16 about 1.7 million hectars of land was covered by wheat and 4.2 million metric tons of wheat grains were harvested (CSA, 2015/16). Arsi and Bale highlands in South- Eastern Ethiopia are the major common wheat producing zones in the country and are considered the wheat belts of East Africa. However, quantitative and qualitative yield losses due to diseases are confronting farmers all across the wheat producing regions of the country (Dereje Hailu and Chemeda Fininsa, 2009).

Among the most important diseases of wheat that significantly reduce wheat production are the rusts (yellow, stem and leaf rusts). The rusts of wheat are among the most widely spread diseases that can be found in most areas of the world where wheat is grown. They are spread in the form of clonally produced dikaryotic urediospores, which can be dispersed by wind for thousands of kilometers from initial infection sites across different areas even from continent to continent. Epidemics of wheat rusts can occur on a continental scale due to the widespread dispersal of urediospores (Khan *et al*., 2013).

Wheat rust fungi are highly specific obligate parasites. Rust populations can be characterized by distribution of races and the frequencies of virulence against specific rust resistance genes on a defined set of wheat differential hosts (Khan *et al*., 2013). Wheat leaf, stripe and stem rusts have devastating role in reducing crop yield resulting in socio-economic instability many times across the world. The semi-dwarf wheat varieties with race specific resistance could not survive longer due to the evolution of new rust races (Rehman *et al*., 2013).

Stripe rust probably occurred long before wheat was grown for food, the disease was first described by Gaddin Europe in 1777 and it has been reported in more than 60 countries on all continents except Antarctica (Chen, 2005). Stripe rust prevalence changes from year to year and from place to place, depending on climatic conditions and variety grown (Teklay Abebe *et al*., 2013). Major stripe rust epidemics occurred in Ethiopia in 1970's, 1988, 2010 (Nazari, 2011). In the Bale highlands, wheat is produced twice a year favoring the continuous perpetuation of the three rust pathogens year round. Rust monitoring conducted over 1996 to 2000, and surveys indicated that the disease is more important, endemic and severe in the main season (August to December) than in short season (March to July) (Dereje Hailu and Chemeda Fininsa, 2009). The development of yellow rust epidemics, in addition to favorable weather factors, depends on the level of cultivar susceptibility, which affects the disease occurrence and its progress, cropping systems and management practices (Dereje Hailu and Chemeda Fininsa, 2009). This situation provides the pathogen not only with a substrate both in area and time, but also results in successive evolution of pathotype lineages and/or new races of the pathogen (Kebede Tadesse *et al.*, 2011).

In 2010 more than 400,000 ha of wheat were affected by yellow rust which led to serious losses, though difficult to measure. The epidemic covered almost all wheat growing regions in the country except Tigray Regional State (Nazari, 2011). Most of the commercial bread wheat cultivars were susceptible to yellow rust (Nazari, 2011).

Stem rust caused by *Puccinia graminis f. sp. tritici* is amongst the biotic factors which can cause up to 100% yield loss in Ethiopia if susceptible cultivars are grown and epidemics occur early (Efrem Bechere *et al*., 2000). Stem rust isolates with virulence to Sr9e and Sr13 were first reported in Ethiopia in 1988 and 1989, respectively, (Mengistu Hulluka *et al*., 1991). The East African highlands are a known “hot-spot” for the evolution and survival of new rust races (Singh *et al*., 2008). A total of nine races were identified, which include TTKSK, TTKTF, TTKTK, JRCQC, TKTTF, TTKSC, TRTTF, SRKSC and RRKSF (Endale Hailu *et al*., 2015). Race TTKSK was dominant and widely distributed in the Oromia and Amhara regions with 52% frequency while; it was not found in Tigray region (Endale Hailu *et al*., 2015). The most virulent and new race, TKTTF which causes localized stem rust epidemic in Bale and Arsi was predominantly distributed in Oromia region with 36.4% frequency(Endale Hailu *et al*., 2015).

Leaf rust (*Puccinia triticina* Eriks.) of wheat is the most common and widely distributed of all the cereal rusts (Kolmer, 1996) and accounts for major yield losses every year (Kolmer *et al*. 2003). In Ethiopia leaf rust is not a devastating disease compared to yellow and stem rust but, it has the potential to constrain wheat production in South-eastern parts of Ethiopia (Daniel Kasa *et a*l, 2015). Leaf rust was observed in the mid-altitude and in the lowland wheat producing areas of East Hararge (Samuel Tegene *et al*, 2014). In northern parts of Ethiopia, the severity and incidence of leaf rust reached 100% on susceptible wheat varieties during suitable environmental condition for leaf rust development (Teklay Abebe *et al*., 2015).

The three rusts are known to occur all over the world, in areas where wheat is produced but their damage depends on the environmental conditions and the types of cultivars grown.

Infection can occur anytime from the one-leaf stage to plant maturity provided plants are still green (Chen, 2005). The discovery of genetic resistance by Biffen (1905), physiological specialization in the rust by Stakman and Levine (1992), and the gene for gene interaction theory by Flor (1959), and the use of race specific types of resistance has been dominating rust resistance in wheat improvement programs. However, resistance based on single race-specific genes often becomes ineffective within few years producing “boom and bust” cycles in wheat production. The “bust” cycles (when rust resistance has been overcome) are caused by pathogens mutating to acquire virulence, virulent races migrating into a new region or the appearance of races favored by selection pressure from the existing pathogen population (Zhengi, 2002).

Multi-location disease testing of germplasm is used to obtain data to support breeding strategies aimed at broadening the genetic base of resistance by International Maize and Wheat Improvement Centre (CIMMYT), International Centre for Agricultural Research in Dry Areas (ICARDA) and Ethiopian Institute of Agricultural Research (EIAR). Wheat cultivars are released for production without carrying out tests against triple rusts. As a result, the current work was carried out to test wheat lines before release at field and in green house at seedling stage to different isolates and races of triple rusts and reduce the rusts problem.

The objectives of the current work were:

General objective:

To contribute towards increasing the productivity of wheat in the study areas through selecting wheat genotypes for resistance against triple or the major rusts.

Specific objectives:

- ✓ To detect the prevailing virulence of stem,leaf and yellow rusts in central and southeastern Ethiopia
- ✓ To evaluate wheatlines for resistance to triple rusts

2. LITERATURE REVIEW

2.1. History and origin of wheat

Wheat is believed to have originated in South-western Asia. Some of the earliest remains of the crop have been found in Syria, Jordan, and Turkey (Heun *et al*.,1997). Primitive relatives of present day wheat have been discovered in some of the oldest excavations of the world in eastern Iraq, which date back to 9,000 years and other archeological findings show that bread wheat was grown in the Nile Valley about 5,000 B.C. as well as in India, China, and even England at about the same time (Anonymous,2015c).

The domestication of wheat around 10,000 years ago marked a dramatic turn in the development and evolution of human civilization, as it enabled the transition from a hunter gatherer and nomadic pastoral society to a more sedentary agrarian one (Eckardt, 2010). Two of the most important traits in the evolution of bread wheat and other cultivated grasses were an increase in grain size and the development of no shattering seed (Eckardt, 2010).

Wheat is grown on more land area worldwide than any other crop and is a close third to rice and corn in total world production (https://books.google.com/books?isbn=0495556718). Wheat is well adapted to harsh environments and is mostly grown on windswept areas that are too dry and too cold for the more tropically inclined rice and corn, which do best at intermediate temperature levels (Njau *et al*., 2011).

The collection and evaluation of indigenous wheat and the introduction of exotic germ-plasms for testing under local conditions in Ethiopia began in early 1930s (Hailu Gebre-Mariam, 1991). During this period, several wheat varieties were introduced from Europe and yielded satisfactorily until they succumbed to diseases. On the other hand, the local varieties produced consistent and reasonable yields because of their good adaptation. As a result, good quality local wheat were grown at Ambo, Dese, Gonder, Holetta, around Addis Ababa, Bishoftu and Debre Berhan areas during this period (Hailu Gebre-Mariam ,1991). Now a day's wheat production in Ethiopia increases from time to time in production and area coverage. In 2015/16 production season 44 zones and 4 woredas produced wheat (CSA, 2015/16). Climate-based analyses suggest that the greatest opportunity for expanding wheat production area in Ethiopia would involve increasing the tolerance of wheat to warmer growing conditions; this means both heat tolerance and resistance to pathogens and pests of warmer climates (Jeffrey *et al.*, 2001).

2.2. Wheat production and Distribution

Wheat has had an important role in the development of agriculture across the world, and has spread from the Middle East and Europe across the globe (Snape & Pankova, 2006). Wheat is probably the most widely adapted crop being grown from high altitude regions near the equator, to high northern and low southern latitudes in Scandinavia and southern parts of South America. The reason for this wide adaptability is the presence of genetic variation in the species which allows different strains to flower and set seed under different day length and temperature regimes, and to survive harsh winters and high summer temperatures (Snape & Pankova, 2006).

In most parts of the country, only a single wheat crop is grown during the second, longer rainy season (meher) which usually starts in June. The short rains (belg), starting in March, are less reliable in most parts of Ethiopia. Growing wheat in belg season implies harvesting during meher, which often results in high grain moisture levels and sprouting. Thus, wheat crops are typically sown by broadcasting in June or July and harvested in November or December (White *et al*., 2001). The regions identified as highly suitable for wheat production in Ethiopia include Arsi; South, West and North Shewa; Ilubabor; West Harerge; Sidama; Tigray; North. Gonder; Bale and Gojam (Hailu Gebre-Mariam, 1991).

Currently national and regional research centeres and agricultural extension pushes wheat production into new areas including agro pastoralist areas of Afar and Somali to address wheat demands of the areas using irrigation. Bread wheat occupies nearly 60% of the total wheat area and its cultivation is expanding rapidly due to its high yield and wide adaptability (Woubit Dawit, 2008). The indigenous durum wheat with few pocket areas of emmer wheat production accounts for the remaining 40% of the total wheat area (Woubit Dawit, 2008).

2.3. Origin and distribution of rusts

2.3.1. Stem rust (*Puccinia. graminis f.sp. tritici*)

Stem rust has been a serious disease of wheat, barley, oat and rye, as well as various important grasses including timothy, tall fescue and perennial rye grasses (Kurt J. *et al*., 2005). One hundred wheat stem rust samples were collected in 2013 cropping season in the Oromia, Amhara and Tigray region resulting in identification of nine races: TTKSK(Ug99), TTKTF, TTKTK, JRCQC, TKTTF, TTKSC, TRTTF, SRKSC and RRKSF (Endale Hailu *et al*., 2015).

Race Ug99 of the fungus *Puccinia graminis f.sp tritici* that causes stem or black rust disease on wheat was first detected in Uganda in 1998 (Singh *et al*.,2006). Seven races belonging to the Ug99 lineage are now known and have spread to various wheat growing countries in the eastern African highlands, as well as Zimbabwe, South Africa, Sudan, Yemen, and Iran (Singh *et al*., 2011). Because of the susceptibility of 90% of the wheat varieties grown world-wide, the Ug99 group of races was recognized as a major threat to wheat production and food security (Singh *et al*., 2011). Its spread, either wind-mediated or human-aided, to other countries in Africa, Asia, and beyond is evident (Singh *et al*., 2011).

2.3.2. Leaf rust (*Puccinia triticina*)

The evolutionary history of the obligate rust pathogen on wheat, *Puccinia triticina*, is correlated with adaptation to hosts with different ploidy levels (Liu *et al*., 2013). Phylogenetic analyses (parsimony, Bayesian, maximum likelihood) showed the clear initial divergence of *P. triticina* isolates collected from *Aegilops speltoides* (the likely B genome donor of modern wheat) in Israel from the other isolates that were collected from tetraploid (AB genomes) durum wheat and hexaploid (ABD genomes) common wheat (Liu *et al*., 2013). Coalescence-based genealogy samplers also indicated that *P. triticina* on *A. speltoides*, diverged initially, followed by *P. triticina* isolates from durum wheat in Ethiopia and then by isolates from common wheat (Liu *et al*., 2013). Isolates of *P. triticina* found worldwide on cultivated durum wheat were the most recently coalesced and formed a clade nested within the isolates from common wheat (Liu *et al*., 2013). By a relative time scale, the divergence of *P. triticina* as delimited by host specificity appears very recent. Significant reciprocal gene flow between isolates from common wheat and isolates from durum wheat that are found worldwide was detected, in addition to gene flow from isolates on common wheat to isolates on durum wheat in Ethiopia (Liu *et al*., 2013).

2.3.3. Yellow rust/stripe rust (*Puccinia striiformis f.sp tritici*)

Yellow/stripe rust which is caused by *Puccinia striiformis* f.sp.*tritici*. However, the worldwide population structure and the center of origin of the pathogen were still unknown (Justesen *et al*., 2014). Analyses of linkage disequilibrium and genotypic diversity indicated a strong regional heterogeneity in levels of recombination, with clear signatures of recombination in the Himalayan (Nepal and Pakistan) and near-Himalayan regions (China), and a predominant clonal population structure in other regions (Justesen *et al*., 2014).The higher genotypic diversity, recombinant population structure and high sexual reproduction ability in the Himalayan and neighboring regions suggests this area as the putative center of origin of *Puccinia striiformis* f. sp. tritici (PST) (Justesen *et al*., 2014). Justesen *et al* (2014) used clustering methods and approximate Bayesian computation (ABC) to compare different competing scenarios describing ancestral relationship among ancestral populations and more recently founded populations. Their analyses confirmed that the Middle East-East Africa as the most likely source of newly spreading, high- temperature-adapted strains; Europe as the source of South American, North American and Australian populations; and Mediterranean-Central Asian populations as the origin of South African populations (Justesen *et al*., 2014). The existence of a high genotypic diversity, a high sexual ability as well as the independent maintenance of strongly differentiated populations in the Himalayan region pinpoint this region as the possible centre of origin of PST (Sajid, 2013).

2.4. Common signs and symptoms of wheat rusts

Stripe/yellow rust appears as a mass of yellow to orange urediniospores erupting from pustules arranged in long, narrow stripes on leaves (usually between veins), leaf sheaths, glumes and awns on susceptible plants. Resistant wheat cultivars are characterized by various infection types from no visual symptoms to small hypersensitive flecks to uredinia surrounded by chlorosis or necrosis with restricted urediniospore production. On seedlings, uredinia produced by the infection of a single urediniospore are not confined by leaf veins, but progressively emerge from the infection site in all directions, potentially covering the entire leaf surface (Chen *et al*., 2014).

The symptoms of stem rust on wheat appear as elliptical blisters or pustules, known as uredia that develop parallel with the long axis of the stem, leaf, or leaf sheath. Blisters may also appear on the neck and glumes of the wheat spike. The epidermis covering the pustules is later ruptured irregularly and pushed back, revealing a powdery mass of brick red-colored uredospores. The uredia vary in size from 1 to 3 millimetres wide by 10 millimetres long. Later in the season, as the plant approaches maturity, the pustules turn black as the fungus produces teliospores instead of uredospores and uredia are transformed into black telia. Sometimes telia may develop independently of uredia. Uredia and telia may exist on wheat plants in such great numbers that large parts of the plant appear to be covered with the ruptured areas, which are filled with the rust red uredospores, the black teliospores, or both. On barberry, the symptoms of stem rust appear as yellowish to orange-colored spots primarily on the leaves. Within the spots, and in leaves generally on the upper side, appear a few minute, orange-colored bodies, the spermagonia, usually bearing a small droplet of liquid or nectar. Beneath the spermagonia, and occasionally next to them, groups of orange-yellow horn- or cup-like aecia appear (Agrios, 2005).

Leaf rust is generally found on leaves but may also infect glumes and awns. Symptoms begin as small circular to oval yellow spots on infected tissue of the upper leaf surface. As the disease progresses, the spots develop into orange-colored pustules that may be surrounded by a yellow halo. The pustules produce a large number of spores that are easily dislodged from the pustule, resulting in an "orange dust" on the leaf surface or on clothes, hands, and equipment. As the disease progresses, black spores may be produced, resulting in a mixture of orange and black lesions on the same leaf. Leaf rust is characterized by red pustules or uredinia scattered on infected leaves (Fetch *et al*., 2011).

Table 1.The most distinguishing features of the three wheat rusts

Pustule character	**Stripe rust**	**Leaf rust**	**Stem rust**
Colour	✓ Yellow	✓ Orange brown	✓ Reddish brown
Shape	✓ Small,circular, densely packed on seedling leaves and in yellow stripes running along the leaf in older plants	✓ Circular to oval in random pattern on leaf	✓ Oval to elongated with conspicuously tattered edges, random pattern on leaf
Location on plant	✓ Chiefly on upper surface of leaf but also on leaf sheaths, awns and inside of glumes (head infection)	✓ Chiefly on upper surface of leaf and leaf sheaths	✓ On both sides of leaf, on leaf sheaths, stems and outside of head

2.5. Host ranges of rusts

Puccinia striiformis (Pst) has its hosts in the cereal group; wheat and barley are the principal hosts. Several wild grasses can harbor stripe rust pathogenic to wheat and barley but their role in the epidemiology of stripe rust differs from area to area (Roelfs & Bushnell, 1985). Additionally barberry serves as host for yellow/ stripe rusts (Hansen *et al*., 2013). Pst mainly infects common wheat (*Triticum aestivum* L.), durum wheat (*T. turgidum* var. durum L.), cultivated emmer wheat (*T. dicoccum* Schrank), wild emmer wheat (*T. dicoccoides* Korn) and triticale (*Tritico secale*). It can infect certain cultivated barleys (*Hordeum vulgare* L.) and rye (*Secale cereale* L.) but generally does not cause severe epidemics. In addition, it may infect naturalized and improved pasture grass species, such as *Elymus canadensis* L., *Leymus secalinus* Hochst, *Agropyron* spp. *Garetn*, *Hordeum* spp. L., *Phalaris* spp. L and *Bromus unioloides* Kunth. Pycnial/aecial (alternate) hosts are Barberry(*Berberis chinensis*, *B. koreana*, *B. holstii*, *B. vulgaris*, *B. shensiana*, *B. potaninii*, *B. dolichobotrys*, *B. heteropoda*, etc.) and Oregon grape (*Mahonia aquifolium*) (Chen *et al*., 2014).

Hosts for leaf rust (*Puccinia triticina* Eriks) are common wheat (*Triticum aestivum*.L), durum wheat (*T. turgidum* L.var durum), cultivated emmer wheat (*T.dicoccon*), wild emmer wheat (*T.dicoccoides*), *Aegilops speltoides*, goat grass (*Ae.cylindrica*) and Triticale (*X.triticosecale*) and the alternate host for leaf rust of wheat is *Thalictrum speciosissimum* (*T.flavum Glaucum*) and *Isopyrum fumaroides* (Melvin *et al*., 2008).

Puccinia graminis, causal agent of stem rust on wheat, barley, and oat, has a complex heteroecious life cycle with species in the Triticeae being telial/uredinial stage primary hosts (Leonard and Szabo, 2005). *Berberis vulgaris* can serve as alternate hosts for stem rust

(Roelfs *et al*.,1992). *Lolium temulentum* and *Setaria pumila* were identified to be secondary hosts for wheat stem rust (CIMMYT, 2000).

2.6. Diseases development

The presence of a pathogen against a particular plant will generally not cause serious diseases unless the environmental conditions are favorable. The following conditions are the requirement for wheat rust diseases development.

Table 2. Environmental conditions required for wheat rusts

	Temperature (°c)				
Stage	Minimum	Optimum	Maximum	Light	Free water
		Leaf rust			
Germination	2	20	30	Low	Essential
Appressorium	-	15-20	-	Non	Essential
Penetration	10	20	30	No effect	Essential
Growth	2	25	35	High	Non
Sporulation	10	25	35	High	Non
		Stem rust			
Germination	2	15-24	30	Low	Essential
Appressorium	-	16-27	-	Non	Essential
Penetration	15	29	35	High	Essential
Growth	5	30	40	High	Non
Sporulation	15	30	40	High	Non
		Yellow rust			
Germination	0	9-13	23	Low	Essential
Appressorium	-	-	Not formed	Non	Essential
Penetration	2	8-13	23	Low	Essential
Growth	3	12-15	20	High	Non
Sporulation	5	12-15	20	High	Non

Source: (Roelfs *et al*., 1992).

2.7. Yield losses caused by rusts

Rust symptoms are confusing for farmers due to lack of agricultural pest information. Even though the farmers are capable of controlling wheat rusts through chemical management they are not effective in overcoming the disease problem due to unwise use and incorrect rate of fungicides. Yield losses inflicted by rusts depend on the level of resistance and susceptibility of varieties for rusts and also the climatic condition of the production season in a given area.

In Pakistan yield loss assessment was done and 5.77% yield loss was recorded on the resistance variety (Inquilab-91). Whereas Morocco, proved to be the most susceptible wheat variety to yellow rust with maximum yield deficit to the tune of 39.79% in Pakistan (Bashir *et al*.,2007). Yield losses ranging between 1.96 % in the wheat cultivar Gemmeiza 7 to 8.21 % in the wheat cultivar Misr 1 was recorded due to stem rust in Egypt (Mamdouh *et al.*, 2013).

In Ethiopia yellow rust yield loss was assessed on superimposed trials of wheat and the result from the assessment indicated that Grain yield losses of 47.2% and 32% were observed in the worst scenario in north Shewa and in east Gojam zones, respectively (Landuber Wendale *et al*., 2016). Grain yield loss was lowest (28%) for south Gondar zone (Landuber Wendale *et al*., 2016).

Yield losses due to stem rust reached 29% on variety Sirbo and 21.1% on Maddawalabu in 2005 at Agarfa. In 2006, grain yield losses were 25.7% on Sirbo and 18.6% on Maddawalabu. In 2006, the disease reduced grain yield by 22.1% on Sirbo and 18.1% on Maddawalabu (Kebede Tadesse *et al*., 2010). The epidemic, which developed in December 1993 and spread rapidly throughout the regions where Enkoy was grown, reduced Enkoy yields by 65 to100 percent (Shank 1994). In the highland wheat areas, yields were reduced by an estimated 42 percent by the epidemic. Total susceptibility and 100 percent yield loss due to stem rust was noted in a fungicide experiment conducted on Enkoy at Kulumsa Agricultural Research Center, in the following year (Ayele Badebo and Temesgen Kebede 1996).

Yield losses due to leaf rust is significant and estimated to reach 30– 70% or even greater on susceptible varieties depending on the environmental condition and inoculum pressure (Murray et al., 1994). In Ethiopia even if leaf rust has limited effect on wheat production, it resulted in 75% yield loss during epidemic condition (Teklay Abebe, 2015).

2.8. Rust management

2.8.1. Cultural

No single practice is effective under all conditions but using a series of cultural practices greatly enhances the existing resistances. Removing the green bridge with tillage or herbicides is an effective control measure for epidemics that would result from endogenous inoculums, gene deployment (which can be obtained by a grower if more than one cultivar are used that differ in resistance and from those grown by immediate neighbors), control of timing and frequency and amount of irrigation and fertilization applications (Roelfs *et al*.,1992). Practices such as changing planting dates, destroying alternate host plants, using multi-lines or varietal mixtures are also used in rust management (Wiik, 2009).

2.8.2. Chemical

Foliar fungicides can effectively control stripe rust. Applied when the crop is at the boot stage of development, the fungicides should provide protection for the upper leaves that contribute most of the energy used to produce grain. Products belonging to the strobilurin class of fungicides (Headline, Quadirs) provide excellent activity against stripe rust but are most effective when applied before infection. If stripe rust is already present in a field at the time of application, it is better to use products belonging to the triazole class of fungicides (Folicur, Prosaro, Tilt) or premixes of the two classes (Quilt, Stratego, Twinline). The triazole class of fungicide is generally considered to have stronger curative activity. Four active ingredients are currently registered as seed treatments for the control of stripe rust in seedlings: flutriafol, triadimenol, triticonazole and fluquinconazole (Murray *et al*., 2005). Nativo 300 SC (trifloxystrobin 100 g L-1 + tebuconazole 200 g L-1) and Prosaro 250 EC (prothioconazole 125 g L-1 + tebuconazole 125 g L-1) applied at the rate of 1.0 L ha-1 were recommended to control stem rust in Kenya (Joseph *et al*., 2013). Chlorothalonil, Cyproconazole, Fenpropimorph, Flusilazolec, Flutriafol, Prochloraz, Propiconazole and Triadimenol are fungicides used to control leaf and yellow rust in United Kingdom (England) (Cook *et al*., 1999). As indicated in the table 3 below following commonly used fungicides were verified and used in Ethiopia.

Table 3. Major fungicides used to control rusts in Ethiopia

No	Trade names	Common names	Recommended
1	Rex duo	Epoxiconazole+ Thiophanate-methyl	✓ Stripe rusts
2	Natura 250 EC	Tebuconazole	✓ Stripe rust
3	Bumper 25 EC	Propiconazole 25%	✓ Stem and Leaf rusts
4	Bayleton 25 WP	Triadimefon 250 g/l	✓ Stem, Leaf and Stripe rusts
5	Tilt 250 EC	Propiconazole	✓ Stem , Leaf and Stripe rust
6	Topzol 250 EC	Propiconazol 25% EC	✓ Stripe rust

Source (MoA, 2014)

Note: EC= Emulsified concentrate WP= Wettable powder

2.8.3. Host plant resistance

Genetic resistance is the main method for controlling obligate parasites. However, effective disease control requires that durable, race nonspecific resistance is incorporated into high yielding genotypes. In some areas, a shift in breeding strategies towards this durable type of resistance, based on minor additive genes, is required to avoid the ‘boom and bust’ cycles that are frequently observed. This is particularly true for areas where a single genotype is sown and the risk of mutation to new virulent races increases under selection pressure (Duveiller *et al*., 2007). Two types of genetic resistance to rusts are known: a) seedling resistance and b) adult plant resistance. Seedling resistance, which is controlled by a single gene, is highly effective and lasts throughout the wheat life cycle (Martinez *et al*., 2012). Virulence analysis of leaf rust (*Puccinia recondita*) showed that 10 “Lr” resistance genes (Lr1, Lr2a, Lr9, Lr15 , Lr19 , Lr24 , Lr25 , Lr26 , Lr28 , and Lr29) were effective on bread wheat, six on durum wheat (Lr1, Lr2a, Lr20 , Lr25, Lr26, and Lr30), and six among these “Lr” genes were effective on both crop species. Red winter wheat cultivars and lines that had seedling resistance genes Lr2a, Lr9, and Lr26 combined with adult plant resistance were highly resistant to leaf rust. Cultivars and breeding lines that had seedling resistance genes Lr1, Lr10, Lr11, and Lr18 combined with adult plant resistance had moderate to low levels of leaf rust resistance in USA (Kolmer, 2004).

Known resistance genes to yellow rust (*Puccinia striiformis f.sp. tritici*) were evaluated for their effectiveness against yellow rust in Syria, Lebanon, Turkey, Tajikistan, Uzbekistan, Iran, Ethiopia, and Yemen. Four resistance genes to yellow rust “Yr” were effective at all sites (Yr8, Yrcv, Yr15, and Yr17). For the diverse climatic conditions and cropping systems in

Center West Asia and North Africa (CWANA), the development of multiple disease resistance is essential (Yahyaoui *et al*., 2000). As indicate from stripe rust differential hosts, virulence was detected for Yr1, Yr2, Yr6, Yr7, Yr8, Yr9, Yr17, Yr18, YrA, Yr18+, Yr21, Yr25, Yr27, Yr27+, Yr27+Yr18, Yr28, Yr29 and Yr31 at Kulumsa field condition and at Arsi Robe field condition, virulence was detected for Yr1, Yr2, Yr6, Yr6+Yr20, Yr7, Yr9, Yr17, YrA, Yr18, Yr18+, YrA+Yr18, Yr21, Yr25, Yr27, Yr27+, Yr27+Yr18, Yr28, Yr29 and Yr31 genes during 2010 yellow rust epidemic (Worku Denbel, 2014). Yr3, Yr5, Yr10, Yr15 and YrSP in synthetic hexaploids are identified as seedling resistance genes and postulated(Sharma & Sharma, 2014). Genes Yr3a, Yr4a, Yr10, Yr17, and Yr26 confer high resistance to the tested Ethiopian isolates. Yr genes Yr6+2, Yr9+2, and Yr24 provide moderate resistance (Woubit Dawit, 2008).Bread wheat cultivars, HAR416, TUSIE (HAR 1407), BATU, DASHEN and GARA, exhibited resistance spectra. Out of the advanced bread wheat genotypes, 8.3.8 (B) and 11.6.24 were released to farmers in Ethiopia, with names KBG-01 and Meraro, during 2001 and 2005, respectively. The former was resistant to the nine races and, based on F2 segregation ratio, two complementary recessive genes, Yr9+ and Yr7 were postulated, (Ayele Badebo *et al*., 2008).

A total of 11 stem rust resistance genes (Sr5, Sr7a, Sr7b, Sr8a, Sr9e, Sr11, Sr21, Sr27, Sr29, Sr30 and Sr37) were postulated to be present either singly or in combination in the durum and bread wheat cultivars and breeding lines in Ethiopia (Belayneh Admassu *et al.*, 2012). Differential lines which carry resistant genes Sr36, SrTmp and Sr24, were effective against the most dominant stem rust race TTKSK (UG99) whereas only Sr11, Sr24 and Sr31 were effective against the most virulence race TKTTF (Endale Hailu *et al*., 2015). Emmer wheat and durum wheat are good source of resistance to wheat rusts (Naod Beteselassie *et al*, 2007).

3. MATERIALS AND METHODS

The study accommodated the phenotyping activity both in the green house and field conditions. It contains 150 wheat lines (93- spring bread wheat lines from Australia, with known gene stocks, Seven checks, 16, 17 and 17 leaf rust, yellow rust and stem rust differential lines, respectively,) were included and about 309 wheat lines from ICARDA including checks were also tested in addition to wheat lines with known genetic stock at Kulumsa.

3.1. Description of the study areas

The study was conducted at three locations in central and southeast of Ethiopia, namely Sinana, Debrezeit and Kulumsa. The three places have different agro ecologies which favor the development of rusts at various degrees. Sinana is well known hot spot area for yellow rust. Kulumsa is hot spot for the three rusts while Debrezeit is hot spot for leaf and stem rusts. Sinana is located at 7° 7’N, 40°10’E and at 2450 masl. It receives mean annual rainfall of 808 mm. The monthly mean minimum and maximum temperatures are 9.3 and 20.9 °C, respectively. The dominant soil type is pellic vertisol which is slightly acidic. Debrezeit research center is located at 08º 44’ N and 38 º 58’ E and at 1900 masl. The area receives mean annual rain fall of 851 mm. The monthly mean minimum and maximum temperatures are 8.9 and 28.3 º C, respectively. The dominant soil type is vertisoil. Kulumsa is located at 39^{0}09’East 08^{0}01’ North and at 2200 m above sea level. It receives 820 mm of rainfall annually. The monthly mean minimum and maximum temperatures are 10.5°C and 22.8°C, respectively. The dominant soil type is clay soil (luvisols).

3.2. Field tests

3.2.1. Planting

Wheat lines were planted in June 2015 at Kulumsa, in July 2015 at Debrezeit and in August 2015 at Sinana using augumented design, along with various differentials and checks. In addition to the aformentioned wheat lines, about 380 wheat lines including checks were planted at Kulumsa. The wheat lines were planted in four blocks with two rows that are 0.2m apart and 2m long using a seeding rate of 100 kg/ha. Fertilizers Urea and DAP were applied at the rate of 50kg/ha and 100kg/ha, respectively. Weed managment and intercultivation was carried out according to the recommendation in each location.

3.2.2. Inoculation

Stem ,leaf and yellow rust spores collected from different fields during previous years were multiplied in the greenhouse using susceptible plants grown in pots during June-August, 2015 were used for inoculating wheat lines at tillering and stem elongation stages. Spreader rows were planted in mixtures of the most susceptible bread wheat cultivars, Morocco, PBW343 and Kubsa in a row around the experimental field. Rust inoculation was made on spreader row which was planted adjusant to the trial on both sides of each block.The inoculation was carried out during tillering stage by spraying and during stem elongation stage by injection method. Spraying of the three rusts on spreader row during tillering stage was done by diluting rust spores with mineral oil and destilled water sprayed to spreader row by pumping (spray) machine after suspension is made by mixing of 0.275g of rusts spore with one liter of mineral oil (soltrol 70) or destilled water. Rusts' injection to spreader row was conducted by mixing the three rusts spore separately with mineral oil and applying the mixture to the spreader row by injecting stem at stem elongation stage using injection syringe.

3.2.3. Data collection and analysis

Field severity data was collection was done on the basis of whole plot. Disease severity as a percentage of leaf area covered with the disease was assessed following a modified Cobb's scale (Peterson *et al*., 1948). Field response was recorded three times at 10 days interval from tillering to soft-dough stage for yellow rust and until late maturity for leaf and stem rusts. The data on disease severity and host reaction was combined to calculate the coefficient of infection (CI) by multiplying the severity value by constant values of 0, 0.2, 0.4, 0.6, 0.8, or 1.0. After the last disease score when the disease progress ceased, according to Stubbs *et al*. (1986): Pathan and Park (2006), the field severity data was converted to Coefficient of Infection (CI) by multiplying with constant values of response. Wheat lines with coefficient of infections ranging from 0 to 20 were considered as resistant while 20 to 30, 30 to 40, 40 to 60 and 60 to 100 were moderately resistant, moderately susceptible, and susceptible, respectively and the weather data were analyzed and plotted using Instat Plus Version 3.37 software.

3.3. Greenhouse tests

3.3.1. Collection, isolation and multiplication of isolates and races of triple rusts

Yellow rust isolates were obtained from samples collected 2015 survey in Arsi and West Arsi. Kubsa isolates of yellow rust were collected from the area where Kubsa was dominantly produced and the isolate was widely distributed in Kubsa Kebele, Gedeb Assasa woreda,West Arsi, Oromia. Digelu isolates were collected from the area where Digelu variety was mostly produced (Lemmuna Bilbilo). Leaf rust isolates were collected from Debrezeit and Kulumsa rust testing sites. The leaf rust isolates used for seedling evaluation were Arendeto and LAG 672 isolates. The stem rust races TTKSK and TKTTF were obtained from Ambo Plant Protection Research Center and multiplied on the susceptible cultivar PBW343 and Digelu variety, respectively.

Fresh and sufficient inoculum was prepared on susceptible hosts. A maleic hydrazide (MH) solution was prepared at a rate of 0.3 g/l. At emergence, seedlings of hosts were treated with a solution of MH to retard plant development and encourage sporulation. Two days after applying MH, seedlings were fertilized with solution as described above. Week old seedlings were infected by spraying with urediniospores of triple rusts in separate greenhouse compartments. Fresh spores of stripe, leaf and stem rust were used from for inoculating the selected hosts. Urediospores were suspended in light mineral oil (Soltrol 70). The upper surfaces of primary leaves were uniformly inoculated with a pressurized sprayer by putting pots in an inoculation booth that was automatically rotating to allow uniform spraying at spore concentration of 0.275g/1l urediospores/ mineral oil. The booth was thoroughly cleaned after spraying and different races were handled separately to prevent contamination. Inoculated seedlings were allowed to dry for about 2 hours before they were incubated. Leaf rust and stem rust inoculated sets were incubated for 16 hours at 20 to 24°C by placing in a moist chamber (96% RH) while the stripe rust set was incubated for 48 hours at 6°C. Seedlings were taken from the moist chambers and allowed to dry slowly for another 2 hours and moved to glasshouse until sufficient spores were harvested for inoculating test plants.

3.3.2. Yellow rust seedling screening procedure and analysis

This experiment was conducted at the Ethiopian Institute of Agricultural Research, Kulumsa Agricultural Research Center. Seedlings were inoculated by spraying the bulk of isolates urediospores suspended in light mineral oil (Soltrol 170) using an automizer when the first leaves were fully expanded. Inoculated plants were allowed to dry for 5 minutes and were fine-misted with water and placed in a wet plastic cage with a small amount of water at the bottom. The inoculated seedlings were incubated at 10ºC for 24 hours in a dew chamber with relative humidity close to 100%. Seedlings were transferred to a greenhouse with mean temperature of about 18ºC. A week after inoculation, 2 grams of nitrogen fertilizer per 100 ml of water was added as liquid fertilizer to each pot.

At seedling, disease assessment was carried out from two replicated experiments to avoid diseases escape: on the 14^{th} days after inoculation using 0–9 scale (Table 4, McNeal *et al*. 1971). Infection types 0-6 were classified as low or resistant while 7-9 scores were considered as high or susceptible infection types (Stubbs, 1985).

Table. 4. Infection types representing 0-9 scale according to Mcneal *et al*. (1971)

Infection type	Host response	Symptoms Immune
0	Immune	No visible uredia
1	Very resistant	Necrotic flecks
2	Resistant	Necrotic areas without sporulation
3-4	Resistant	Necrotic and chlorotic areas with restricted sporulation
5-6	Moderately resistant	Moderate sporulation with necrosis and chlorosis
7-8	Moderately susceptible	Sporulation with chlorosis
9	Susceptible	Abundant sporulation without chlorosis

3.3.3. Leaf rust seedling screening procedure and data analysis

Leaf rust seedling screening was done at Kulumsa Agricultural Research Center green house using two leaf rust isolates during December –January 2015 G.C. Plants were grown in rust-free greenhouse until inoculation. At seven days after planting, when first leaves were fully expanded, the seedlings were gently rubbed between moist fingers and then sprayed with tap water using atomizer in the inoculation chamber, and then inoculated by spraying them with a suspension of urediospores in a light mineral oil carrier. Inoculum concentration was adjusted to 0.275 gr/L. The oil was allowed to evaporate from the leaves for 30–60 min, and the seedlings were placed overnight in a dew chamber at 17°C. They were then transferred to a greenhouse with mean temperature of 20-21°C. At 14 days after inoculation, the wheat lines were scored for infection type (IT) according to the scale of (Stakman *et al*., 1962), where 0:

nearly immune; 1: very resistant; 2: moderately resistant; 3: moderately resistant to moderately susceptible; and 4: very susceptible.

3.3.4. Stem rust seedling screening procedure and data analysis

Wheat seedling screening against stem rust races were done at Ambo Plant Protection Research Center green house during February to June 2016 G.C. Five seeds from each of the wheat cultivars were sown in pots, and grown in a greenhouse. About 0.275 gram Spores of stem rust were suspended in 1 Litter of light mineral oil, and sprayed onto leaves of one week old seedlings. Immediately after inoculation, seedlings were incubated in the dark for 18 hours at 18 ^{o}C; and high (95%) relative humidity in humid chamber. Thereafter, the seedlings were exposed to light for three hours. Then, they were transferred to a growing room and grown constantly at 22 - 25^{o}C temperature and natural light intensity. Disease assessment was carried out 14 days after inoculation using the 0 – 4 infection type (IT) scoring system (Stakman *et al*., 1962). Low infection types (LITs=0-2) were considered resistant, and infection type =2+ as intermediate while high infection types (HITs= 3-4) as susceptible for stem rust.

4. RESULTS

4.1. Detection of the virulence of triple rust prevailing in Southeastern and Central Ethiopia

4.1.1. Stem rust

Stem rust differentials were tested at Kulumsa, Sinana and Debrezeit field conditions to identify the prevailing races. All the tested host differentials, except host differentials with stem rust resistance gene *Sr22* and *Sr30* (Table 5), were affected by stem rust at Sinana. This suggests the absence of stem rust races, *Sr22* and *Sr30*, from Sinana. At Kulumsa, stem rust virulence except *Sr17* and *Sr22* at field were detected while at Debrezeit all tested differential hosts were affected confirming the prevalence of all known virulences of stem rust during the 2015 cropping season in the area.

Table. 5. Stem rust differential lines field response, 2015

			Field response		
No	Host differentials	Sr-genes	Sinana	Debrezeit	Kulumsa
1	ISr6-Ra	6	30S	20SMS	15MS
2	ISr8-Ra	8	15MS	40SMS	15MSS
3	W261Sr9b	9b	40S	50S	30S
4	ISr9d-Ra	9d	10S	20RMR	10S
5	CnsSr9g	9g	60S	70S	70S
6	W261Sr10	10	30S	30SMS	15MS
7	St64Sr13	13	60S	60S	30S
8	Combination VII	17	5MS	25MRMS	0
9	Sr22TB	22	0	10MRMS	0
10	W2691Sr28Kt	28	40S	50SMS	80S
11	BtSr30Wst	30	0	30MSS	5MR
12	Sr31 (Benno)/6*LMPG	31	50S	30MSS	80S
13	CnsSR32 AS	32	20S	15MSMR	20S
14	RL6082	39	20S	30SMS	20S
15	RL6088	40	60S	50S	50S
16	Taf-2	44	5S	20MS	5MS
17	CnSSrTmp	Tmp	10S	10MRMS	5S

Source: *Kulumsa Agricultural Research Center* **Note:** *S= Susceptible MS= Moderately Susceptible MSS = Moderately susceptible and susceptible MR= Moderately resistance SMS=Susceptible and moderately susceptible MSMR=moderately susceptible moderately resistance*

4.1.2. Yellow rust

Differentials lines with *YR5*, *YR8*, *YR15*, *YR17*, *YR27*, AVOCET S, Lassik (-*Yr5*) and Lassik (+Yr5) resistance genes have immune field reaction against yellow rust with the severity values of zero at Kulumsa Agricultural Research Center (Table 6), suggesting the lack of the aforementioned races in the study area. However, at Sinana only differential line with *Yr 15* was immune to yellow rust. The current results also demonstrated the absence of virulence race to *Yr15* both at Kulumsa and Sinana.

Table 6. Yellow rust differential lines field responses, 2015

			Field response	
No	Host differentials	**Yr-genes**	Sinana	Kulumsa
1	YR1/6*Avocet S	1	50S	TrMR
2	YR5/6*AOC CX86.6.1.20	5	30S	0
3	YR6/6*AOC CX94.2.2.25	6	60S	TrSMS
4	YR7/6*Avocet S	7	70S	30S
5	YR8/6*Avocet S	8	60S	0
6	YR9/6*Avocet S	9	60S	TrS
7	YR10/6*Avocet S	10	20S	TrMS
8	YR15/6*Avocet S	15	0	0
9	YR17/3*AOC CX94.8.1.25	17	80S	0
10	YR18/3*AOC CX94.10.1.7	18	60S	TrMR
11	YR26/3*AOC CX96.17.1.	26	20S	TrMR
12	YRSP/6*AOC CX94.14.1.15	Sp	5MS	TrMS
13	YR27/3*AOC CX94.19.1.1	27	40S	0
14	AVOCET R	R	80S	TrMR
15	AVOCET S	S	30S	0
16	Lassik (-Yr5)	-Yr5	TrMS	0
17	Lassik (+Yr5)	+Yr5	TrMS	0

Note: *S= Susceptible MS= Moderately Susceptible MSS = Moderately susceptible and susceptible MR= Moderately resistance SMS=Susceptible and moderately susceptible MSMR=moderately susceptible moderately resistance*

4.1.3. Leaf rust

All the differential hosts planted at Debrezeit and Sinana were affected by leaf rust in both locations (Table 7). This confirmed the prevalence of all known races of leaf rust in both areas. In Kulumsa, Gaza, with the *lr23* resistance gene was the only differential host free from leaf rust. Leaf rust severity was the highest in Debrezeit followed by Kulumsa.

Table 7. Leaf rust differential lines field response, 2015

			Reaction of differentials		
No	Differentials host	Lr-genes	Kulumsa	Sinana	Debrezeit
1	THATCHER	22b	10S	5MS	30S
2	TC*6/CENTENARIO	1	30S	TS	30SMS
3	TC*6/WEBSTER	2a	TMS	TMS	40SMS
4	TC*6/CARINA	B	10S	5MS	30S
5	TC*6/DEMOCRAT	3	40S	10MS	40SMS
6	TC*ANIVERSARIO	3ka	20S	TMS	30SMS
7	TRANSFER/6*TC	9	10S	TMS	40MSS
8	KUSSAR	11	20S	TMS	40MSS
9	SELKIRK/6*TC	14a	20S	TMS	40SMS
10	TC*6/EXCHANGE	10	5S	TMS	50SMS
11	KLEIN LUCERO/6*TC	17	20S	5MS	40SMS
12	TC*7/AFRICA43	18	10S	5MS	30SMS
13	TC*6/RL5404 (RL6044)	21	5MS	TMS	30SMS
14	LEE310/6*TC (RL6012)	7	20S	TMS	NG
15	TC*6/ST-1-25	26	20S	TMS	20SMS
16	GAZA (W277)	23	0	15MS	60S

Source: *Kulumsa Agricultural Research Center*

Note: *S= Susceptible MS= Moderately Susceptible MSS = Moderately susceptible and susceptible MR= Moderately resistance SMS=Susceptible and moderately susceptible MSMR=Moderately susceptible moderately resistance NG= not germinated*

4.2. Frequency distribution of wheat lines reaction to triple rusts under field conditions

4.2.1. Field response of wheat lines at Sinana

Of wheat lines tested in the current experiment, 68, 92 and 106 lines were found to be resistant to yellow, stem and leaf rust, respectively, (Figure 1). The coefficient of infection of the wheat lines varied from 0 (immune) to 20 (moderately resistant) suggesting wide variations among the lines in resistance to triple rusts. Seven wheat lines were moderately resistant to yellow rust at Sinana while six lines showed moderately resistant reaction to stem rust at the same location. But no wheat line fell under the category of moderately resistant and susceptible for leaf rust Sinana. This was due to low pressure of leaf rust in the area. The rest wheat lines (about 31) had coefficient of infection above 30 for yellow rust and hence considered as moderately susceptible to susceptible. Eight wheat lines showed susceptible reaction for stem rust at field condition of Sinana research station during 2015 cropping season. Generally, among tested wheat lines about 75 were resistant to yellow rust with below 30 coefficients of infection and 31 wheat lines were considered as susceptible to yellow rust on the basis of field response with coefficient of infection above 30 at Sinana condition during 2015 cropping season. In the same manner 98 wheat lines were resistant to stem rust and the rest eight wheat lines were susceptible to stem rust at field conditions of Sinana.

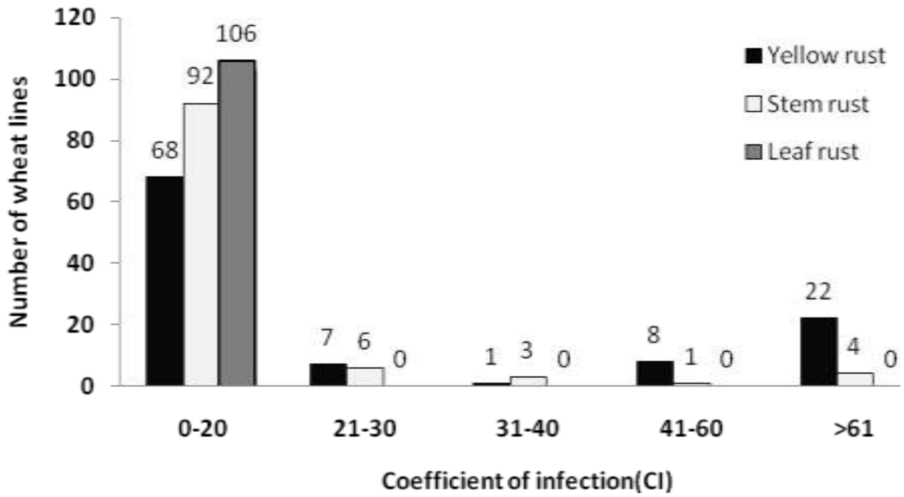

Figure1. Reaction of wheat lines and checks to triple rusts at Sinana, 2015

4.2.2. Field response of wheat lines at Debrezeit

Among tested wheat lines at Debrezeit 29 and 51 gave resistance type of reaction for stem rust and leaf rust, respectively. Twenty and five wheat lines showed moderately resistant types of reaction to stem rust and leaf rust, respectively, on the basis of coefficient of infection. Fifty one and fourty four wheat lines were found susceptible to stem rust and leaf rust, respectively, with coefficient of infection ranging from 30 to 100 (Figure 2). Yellow rust was apparently absent at Debrezeit field condition during the experimental period. This might be because of the unsually low rainfall and high temperature in the area (Appendix figures 1-3).

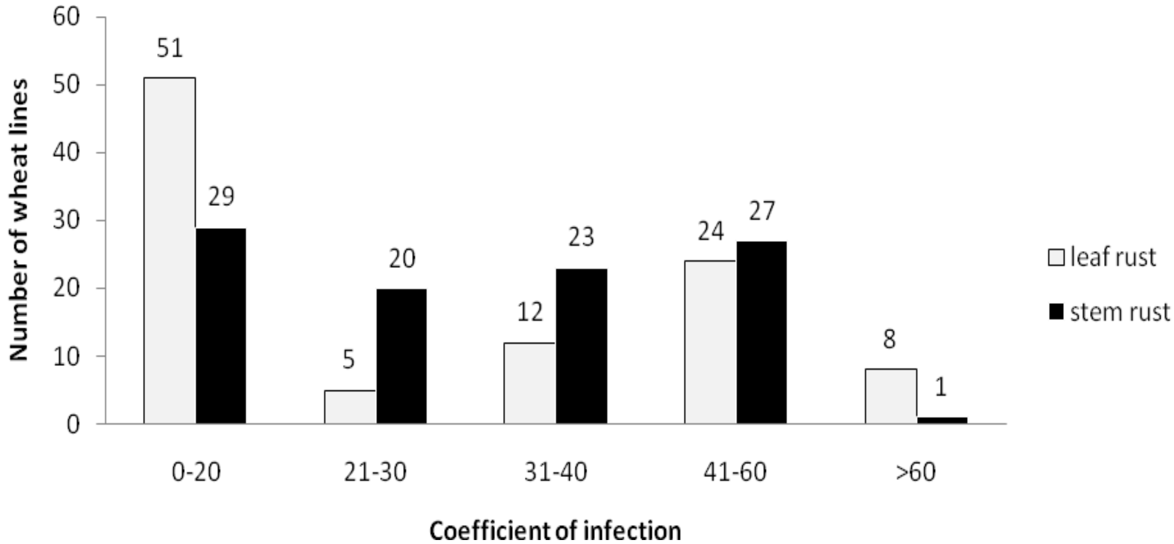

Figure 2. Field responses of wheat lines and checks to stem rust and leaf rust at Debrezeit, 2015

4.2.3. Field response of wheat lines at Kulumsa

At Kulumsa field condition most of the genotypes tested showed low level of infection by triple rusts. As revealed by current results 300,406 and 394 wheat lines including checks have coefficient of infection below 20 to stem rust, yellow rust and leaf rust, respectively, and hence could be considered resistant to the respective rusts (Figure 3). In addition, 28 and 11 wheat lines were categorized as moderately resistant to leaf and stem rusts, respectively, as their coefficient of infection varied between 20 and 30. Further 81, 3 and 4 had CI in excess of 30 and hence could be categorized as susceptible to stem, yellow and leaf rust, respectively.

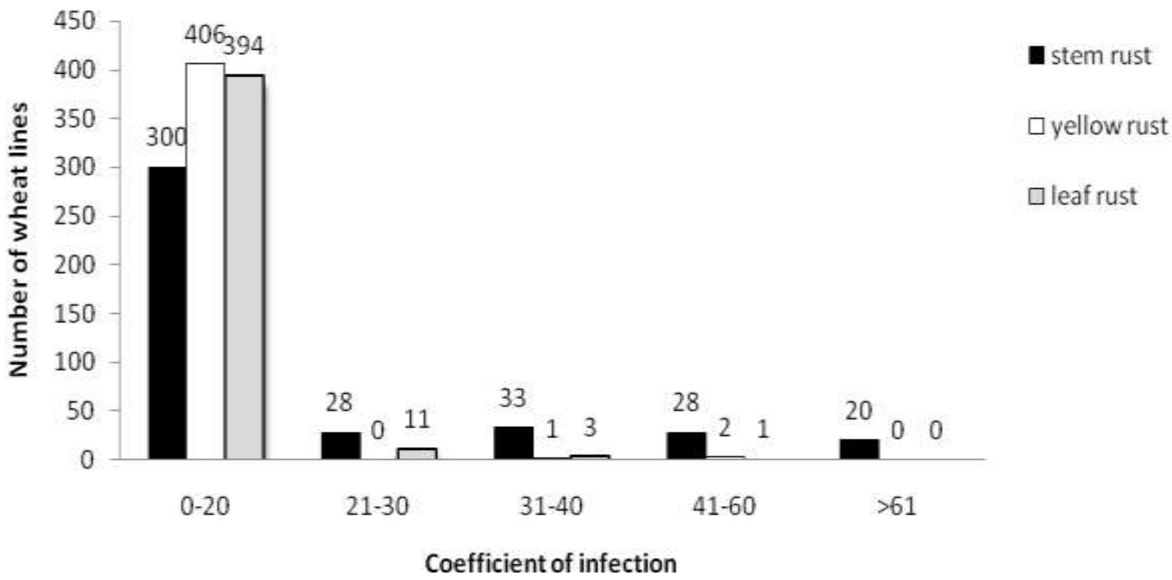

Figure 3. Field responses of wheat lines against triple rusts at Kulumsa, 2015

4.3. Frequency distribution of seedling reaction of wheat lines to triple rusts under green house conditions

4.3.1. Stem rust

Evaluation of wheat lines at seedling stage against stem rust races was done at Ambo Plant Protection Research Center during 2015.

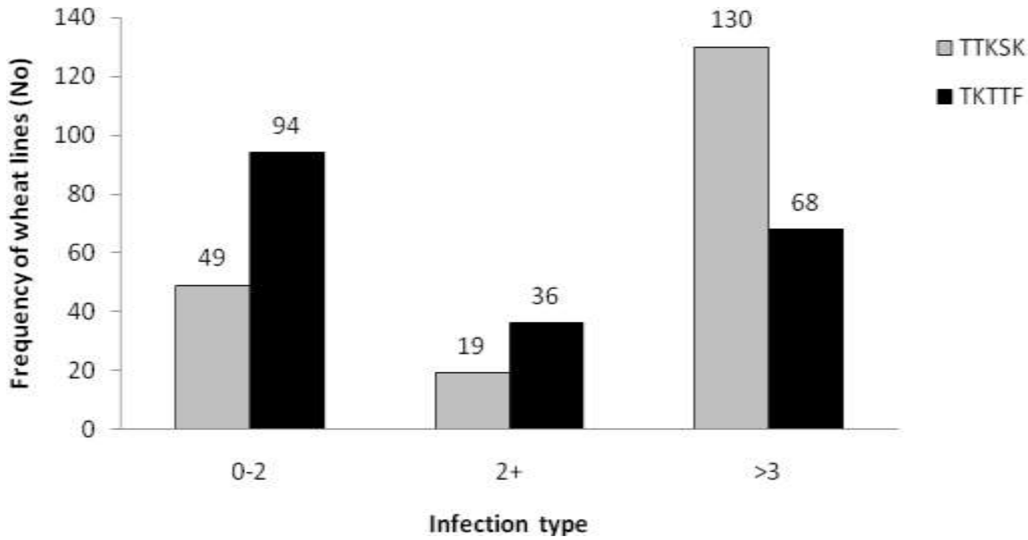

Figure 4 Seedling reactions of wheat lines against the two aggressive stem rust races, 2015

Among the 198 wheat lines tested in the current experiment, 49, 19 and 130 were , respectively, resistant (0-2IT), moderately resistant (2^+ IT) and susceptible (>3IT) to stem rust race (TTKSK), which is known to be the most aggressive and dominant in East Africa (Figure 4). In the same manner the aforementioned wheat lines were subjected to the other currently emerging and devastating stem rust race which was detected in Bale and its surrounding. The result from the evaluation of wheat lines against this Digelu race (TKTTF) revealed that 94, 36 and 68 wheat lines were resistant (0-2IT), moderately resistant (2^+IT) and susceptible (>3IT) to this race, respectively.

4.3.2. Yellow rust

Yellow rust seedling screening was done at Kulumsa Agricultural Research Center greenhouse using two selected yellow rust isolates collected from Arsi region.

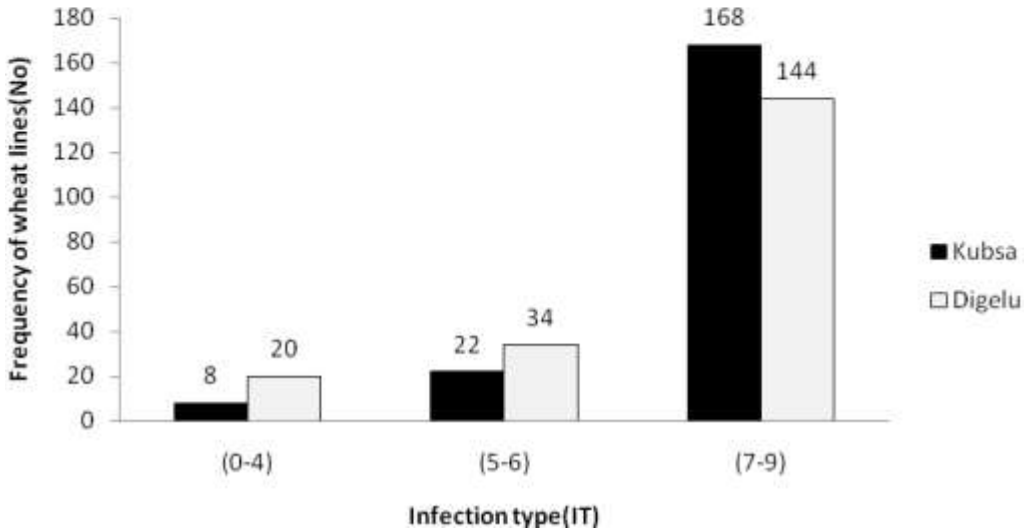

Figure 5. Seedling reactions of wheat lines against the two selected yellow rust isolates, 2015

Results revealed that 8, 22 and 168 wheat lines were resistant (0-4 IT), moderately resistant (5-6 IT) and susceptible (7-9 IT) reaction at seedling stage to Kubsa isolate, respectively, (Figure 5). Besides, 20, 34 and 144 wheat lines exhibited resistant (0-4IT), moderately resistant (5-6IT) and susceptible (7-9 IT) reactions, respectively, to the second isolate (Digalu) used in the current experiment.

4.3.3. Leaf rust

Leaf rust seedling evaluation was done at Kulumsa Agricultural Research Center using two selected leaf rust isolates from Kulumsa (LAG672) and Debrezeit (Arendeto).

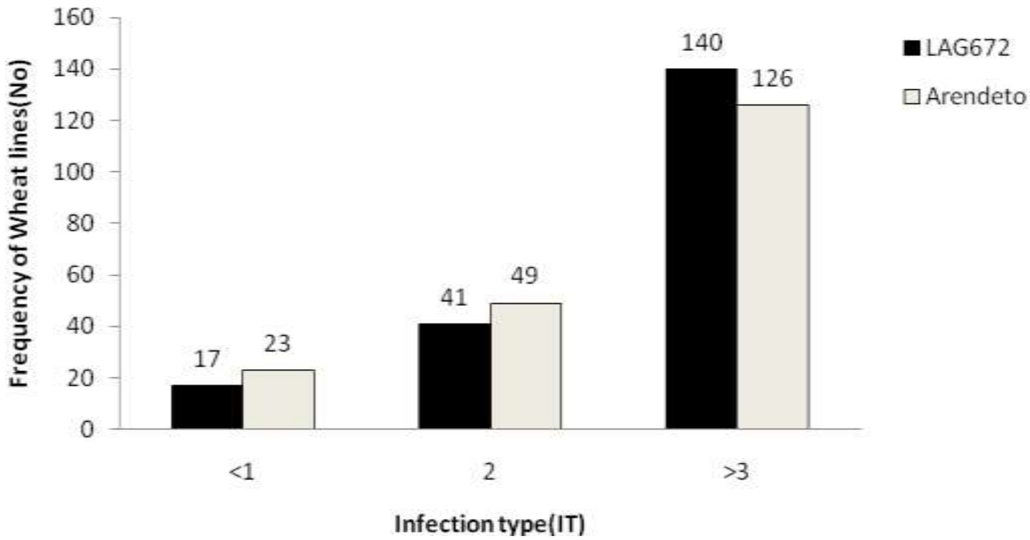

Figure 6. Seedling reaction of wheat lines against the two selected leaf rust isolates, 2015

Among the wheat lines tested in the current experiment, 17, 41 and 140 were resistant (0-1IT), moderately resistant (2IT) and susceptible (>3IT) to leaf rust isolate LAG672 (Figure 6). Additionally, 23, 49 and 126 wheat lines were found to be resistant (0-1IT), moderately resistant (2 IT) and susceptible (>3 IT), respectively, to the leaf rust isolate Arendeto.

4.4. Field and seedling reaction of wheat lines to rusts

4.4.1. Stem rust

Stem rust was severe at two of the three test locations, Debrezeit and Kulumsa. Bigger sized pustules that expand with virtually no limit were predominant on susceptible wheat lines (Figure 7). This led to breaking down of plants before maturity and/or harvest.

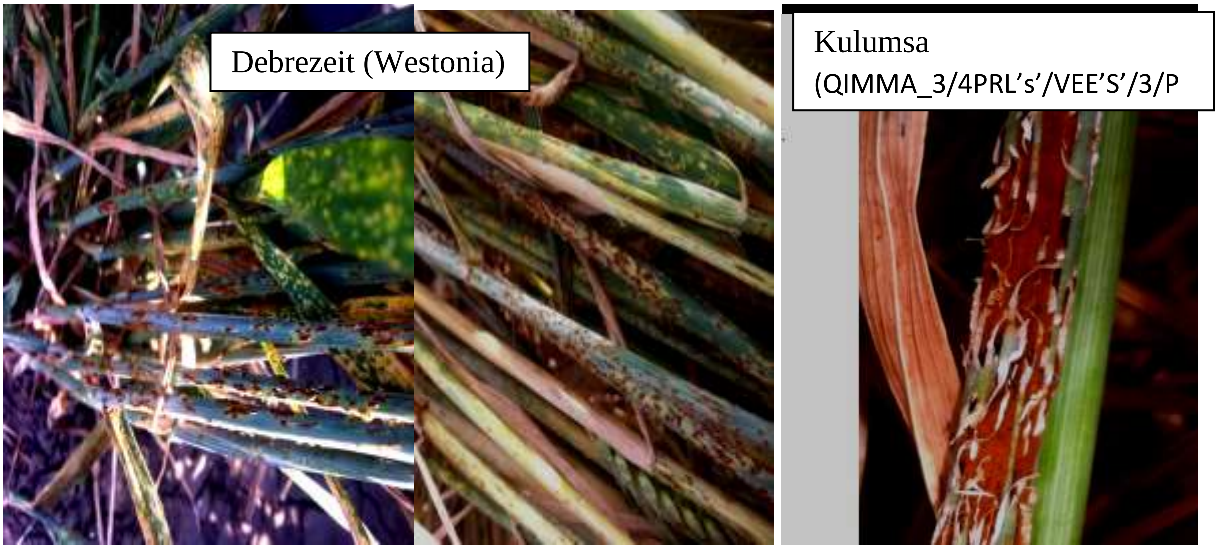

Figure 7. Stem rust at fields of Debrezeit (left) and Kulumsa (right), 2015

CO1 NS 766, WHEA (westonia+ Sr B), Westonia Sr 24+ Sr 26, Co 1 NS 765, Sr 50+Sr 45 # 33, Pavon Sr 24+ Sr 31, Pavon Sr 24+ Sr 50, SA 8123(Sr B), Sr 45/Cs #21, Sr 45+Sr 2/Cs #29, LAG 672, Sr 39, ND Sr 1 and Columbus were found to be immune to stem rust at field conditions of Kulumsa and Sinana. The lowest stem rust infection at Debrezeit was recorded on the wheat line Coins 766. On the other hand, the highest level of stem rust was recorded on wheat lines Westonia across all locations. Of the seven checks tested in the current experiment, Kekeba was the most susceptible while Shorima appeared to have the lowest level of stem rust regardless of location.

Wheat lines with the genetic background of SrB, Sr32, Sr45, Sr50, Sr21, Lr67 and Lr34 in sole were effective in resisting stem rust at field conditions of all the test sites (Table 8). Similarly those which combine the following effective genes: Sr45+Sr2, Sr24+Sr50, Sr45+Sr50, Sr33+Sr45, Sr24+Sr31, Sr26+Sr31, Sr24+Sr31+Sr26, Sr24+Sr26, Sr50+Sr26 and also Sr24+Sr31+Sr50 were effective at field conditions across all the three locations (Kulumsa, Sinana and Debrezeit).

Wheat lines Pavon Sr 24+ Sr 31+Sr 50, WHEA (westonia+ Sr B), Westonia Sr 50+ Sr 26 , Westonia Sr 24+ Sr 26, Angas Sr 32, Sr 50+Sr 45 # 35, Sr 50+Sr 45 # 37, Sr 22/CO 1213, Pavon Sr 24+ SR 26+Sr 31, Sr 45/Kulin, Sr 50+Sr 45 # 10, Sr 50+Sr 45 # 27, Pavon Sr 26+ SR 31, Westonia Sr 24+ Sr 31, Pavon Sr 24+ Sr 31, Gato Sr 50 , Sr 50+Sr 45 # 5, Westonia Sr 24+ Sr 50, Pavon Sr 24+ Sr 50, Quaiv, Av 36-29-18#5, Sr 50+Sr 45 # 1, Avocet, LAG 672 were resistant against stem rust race TTKSK at seedling stage under greenhouse conditions.

Pavon Sr 24+ Sr 31+Sr 50, Angas Sr 32, Westonia Sr 50+ Sr 26, Pavon Sr 24+ SR 26+Sr 31, Pavon Sr 26+ SR 31, Westonia Sr 24+ Sr 31, Pavon Sr 24+ Sr 31, Gato Sr 50, Sr 33+45 # 9, Av 36-29-34# 10, Sr 50+Sr 45 # 5, Sr 45+Sr 2/Cs# 20, Westonia Sr 24+ Sr 50, Pavon Sr 24+ Sr 50, Sr Aes1t, SA 8123(Sr B), Sr 45/Cs #25, Sr 45+Sr 2/Cs# 33, Av 36-29-34#20, Kulin, Sr 50+Sr 45 # 1, Sr 45/Cs #23, Sr 39 and Sr 45/Cs #24, C 591 were the most resistant wheat lines against stem rust race TKTTF.

Pavon Sr 24+ Sr 31+Sr 50, Angas Sr 32, Westonia Sr 50+ Sr 26, Pavon Sr 24+ SR 26+Sr 31, Gato Sr 50, Sr 50+Sr 45 # 5, Westonia Sr 24+ Sr 50 and Pavon Sr 24+ Sr 50 were wheat lines which were highly resistant at the seedling stage (greenhouse) to both TTKSK and TKTTF stem rust races were also found resistant to the disease under field conditions.

Table 8. Responses of wheat lines to stem rust, 2015

		Testing sites							
		Kulumsa		Sinana		Debrezeit		Seedling reaction	
No	Genotypes	Severity	CI	Severity	CI	Severity	CI	TTKSK	TKTTF
1	CO1 NS 766	0	0	0	0	5MR	1	3	2
2	Pavon Sr 24+ Sr 31+Sr 50	5MRMS	3	0	0	10MRMS	2	1	1^{+}
3	AEG 91586 WHEA(westonia+ Sr B	0	0	0	0	10MRMS	2	1	2^{-}
4	Westonia Sr 50+ Sr 26	0	0	TRMS	2.4	5MRMS	4	1^{+}	1^{+}
5	Westonia Sr 24+ Sr 26	0	0	0	0	20MRMS	4	1^{+}	2
6	Angas Sr 32	5MSMR	3	5MS	4	20MRMS	4	1^{+}	1^{+}
7	Shorima	0-5MR	1	TRMS	2	7MS	5	1	1^{+}
8	Co 1 NS 765	0	0	0	0	30MRMS	6	2	3^{-}
9	Sr 50+Sr 45 # 28	TRS	2	0	0	10MRMS	8	2^{-}	2
10	Sr 50+Sr 45 # 33	0	0	0	0	10MRMS	8	2^{-}	2
11	Sr 50+Sr 45 # 35	TRSMS	2	0	0	10MRMS	8	1^{+}	2^{+}
12	Sr 50+Sr 45 # 37	TRS	2	0	0	10MSMR	8	1^{-}	2^{-}
13	Sr 22/CO 1213	5MSMR	3	TRMS	2.4	10MS	8	1^{+}	2
14	CT4-NS1	5SMS	5	0	0	10MS	8	3^{-}	2^{-}
15	Pavon Sr 24+ SR 26+Sr 31	5MR	2	TRMS	2.4	10MSMR	8	1^{+}	1^{+}
16	CO1213	10SMS	10	0	0	10SMS	10	3^{-}	2^{+}
17	CTH- Ns 2	TRS	2	0	0	10SMS	10	3^{-}	2^{+}
18	Sr 45/Kulin	0	0	TRMS	2.4	20MS	16	1^{+}	2^{+}
19	Sr 33+Sr 45 #23	0	0	TRMS	2.4	20MSS	16	2	2
20	Sr 33+Sr 45 #36	TRS	2	TRMS	2.4	20MSS	16	2^{+}	2

Note: *S= Susceptible MS= Moderately Susceptible MSS =Moderately susceptible and susceptible MR= Moderately resistance SMS=Susceptible and moderately susceptible MSMR=moderately susceptible moderately resistance*

Table 8. Continued

		Testing site						Seedling reaction	
		Kulumsa		Sinana		Debrezeit			
NO	Genotypes	Severity	CI	Severity	CI	Severity	CI	TTKSK	TKTTF
21	Sr 50+Sr 45 # 10	0	0	TRMS	2.4	20MSS	16	1^+	2
22	Sr 50+Sr 45 # 27	0	0	TRMS	2.4	20MSMR	16	1^+	2
23	Pavon Sr 26+ SR 31	5MR	2	TRMS	2.4	20MSMR	16	1^+	1
24	Westonia Sr 24+ Sr 31	0	0	TRMS	2.4	20MSMR	16	1^+	1^+
25	Pavon Sr 24+ Sr 31	0	0	0	0	20MSMR	16	1	1^+
26	Gato Sr 50	0	0	TRMS	2.4	20MS	16	1^+	1^+
27	Sr 45+Sr 2/Cs# 32	5MSMR	3	TRMS	2.4	20SMS	20	3	2^+
28	Thatcher+Lr 67	5MR	2	TRMS	2.4	20SMS	20	3^-	3^-
29	Honqolo	0-15SMS	1	TRMS	1	28MS	23	2	3^-
30	Sr 33+45 # 9	TRS	2	TRMS	2.4	30MSS	24	3^-	1^+
31	Av 36-29-34# 10	5MR	2	10MS	8	30MS	24	2^+	1^+
32	Sr 50+Sr 45 # 5	TRMR	1.6	TRMS	2.4	30MS	24	1^+	1^+
33	Sr 50+Sr 45 # 7	0	0	TRMS	2.4	30MSS	24	2^+	2^+
34	Sr 45+Sr 2/Cs# 20	TRMR	1.6	0	0	30MSS	24	3^-	1^+
35	Sr 45+Cocamba	5MSMR	3	0	0	30MSMR	24	2	3^-
36	Sr 21/kulin	5MSMR	3	25S	25	30MSS	24	3^-	2^+
37	Westonia Sr 24+ Sr 50	5MR	2	0	0	30MS	24	1	1
38	Pavon Sr 24+ Sr 50	0	0	0	0	30MS	24	1	1^+
39	Sr Aes1t	30S	30	30S	30	30MSS	24	3^-	1^+
40	SA 8123(Sr B)	0	0	0	0	30MSS	24	2^-	1^+

Table 8. Continued

		Testing site						Seedling reaction	
		Kulumsa		Sinana		Debrezeit			
NO	Genotypes	Severity	CI	Severity	CI	Severity	CI	TTKSK	TKTTF
41	Kingbird	0-20MSS	7	5MS	3	30MSS	24	3^-	3^-
42	Ogolcho	TRMR-20MSMR	4	TRMS	3	30MSS	24	1^+	1
43	Hidasse	5MR-40S	16	10S-20MS	5	28SMS	28	3^-	2^-
44	Sr 45/Cs #20	TRMS	3.2	0	0	30S	30	3^-	2
45	Sr 45/Cs #21	0	0	0	0	30S	30	3^-	2^-
46	Sr 45/Cs #25	TRMR	1.6	0	0	30S	30	3^-	1^+
47	Sr 45+Sr 2/Cs #29	0	0	0	0	30S	30	3^-	2^-
48	Sr 45+Sr 2/Cs# 33	TRS	4	0	0	30SMS	30	3^-	1^+
49	Thatcher+Lr 34	5MSMR	3	5SMS	5	30S	30	3^-	3^-
50	Av 36-29-34#20	5MR	2	10MS	8	40MSS	32	2^-	1
51	Quaiv	10S	10	20S	20	40MSS	32	1	2
52	Av 36-29-18#5	TRMSMR	2.4	10MS	10	40MSS	32	1	2^+
53	Kulin	5S	5	10MS	8	40MSS	32	3	1^+
54	AvYr 5+18	5MR	2	5MS	4	40MS	32	2^+	2^+
55	Sr 50+Sr 45 # 1	0	0	TRMS	2.4	40MS	32	1^+	1^+
56	Sr 45+Sr 2/Cs #28	0	0	TRMS	0	40MSS	32	3^-	1^+
57	Sr 21+Cocamba	10MSMR	6	15MS	12	40MSS	32	2^+	2^-
58	Avocet	5S	5	TRMS	2.4	40MSS	32	1^+	2^+
59	Avocet+Lr 67	10S	10	10MS	8	40MSS	32	2^+	3^-
60	Av Yr 15	TMR	1.6	TRMS	2.4	50MSS	40	3^-	2

Table 8. Continued

		Testing site							
		Kulumsa		Sinana		Debrezeit		Seedling reaction	
NO	Genotypes	Severity	CI	Severity	CI	Severity	CI	TTKSK	TKTTF
61	Sr 33/WT 6/12	5S	5	10MS	8	50MSS	40	3^-	2^-
62	LAG 672	0	0	0	0	40S	40	1^-	3^-
63	Sr 33+Sr 45 #4	15S	15	5MS	4	50MSS	40	2^-	2^-
64	Sr 33/Cs #1	20S	20	30S	30	40S	40	3^-	2^-
65	Sr 33+Sr 2/Cs #15	5SMS	5	15S	12	40SMS	40	3^-	3^-
66	Sr 45/Cs #23	TRMR	1.6	0	0	40S	40	3	1^+
67	Sr 2/ Cs #19	5SMS	5	20S	20	40SMS	40	3	3^-
68	Sr 2/ Cs # 51	10SMS	10	5S	5	40SMS	40	3	3^-
69	Thatcher	10SMS	10	TRS	3	40S	40	3^-	3^-
70	Sr 39	0	0	0	0	40S	40	2^-	1
71	ND Sr 1	0	0	0	0	40S	40	3	2^-
72	Danda'a	0-20SMS	9	15S	15	40SMS	40	3^-	2^+
73	Sr 33/Cs # 2	20S	20	40S	40	50S	50	2^-	3^-
74	Sr 33/Cs #5	10S	10	20S	20	50S	50	3^-	2^+
75	Sr 33+Sr 2/Cs # 11	10S	10	10S	10	50SMS	50	3^-	2
76	Sr 33+Sr 2/Cs #12	10S	10	20S	20	50SMS	50	3^-	3^-
77	Sr 33+Sr 2/Cs #13	10S	10	5MS	4	50S	50	2^+	2^-
78	Sr 33+Sr 2/Cs #14	5S	5	15MS	12	50SMS	50	3^-	3^-
79	Sr 45/Cs #24	0	0	TRMS	2.4	50SMS	50	3^-	1^+
80	Sr 2/ Cs #48	10SMS	10	5MSS	5	50S	50	3^-	3^-

Table 8. Continued

		Testing site						Seedling reaction	
		Kulumsa		Sinana		Debrezeit			
NO	Genotypes	Severity	CI	Severity	CI	Severity	CI	TTKSK	TKTTF
81	Sr 2/ Cs # 52	5S	5	10MSS	8	50S	50	3^-	3^-
82	Cs #39	15S	15	10S	10	50S	50	3	3^-
83	Sr 2+Cs 49	10SMS	10	20S	20	50S	50	3	3^-
84	Cs # 41	20S	20	30S	30	50S	50	3	3^-
85	CS # 42	30S	30	10S	10	50S	50	3^-	3^-
86	Cocamba	5MSMR	3	15S	15	50S	50	3^-	3^-
87	Thatcher+Lr 46	15S	15	20MS	16	50SMS	50	3^-	3
88	CANTHACHK	5MR	2	0	0	50SMS	50	2^+	2
89	Columbus	0	0	0	0	50S	50	3^-	2^+
90	Wes+S46 (B4)	40S	40	80S	80	60S	60	3	3^-
91	Sujata	5SMS	5	70S	70	60S	60	3	3^+
92	C 591	20S	20	60S	60	60S	60	3	1
93	WT6/12	5SMS	5	5MS	4	60S	60	3^-	2^+
94	Wes+ S46(C5)	80S	80	80S	80	60S	60	3^-	2^+
95	Sr 33/Cs # 4	5S	5	20S	20	60S	60	2^+	2^+
96	Sr 33/Cs # 6	10S	10	40S	40	60S	60	3^-	2^+
97	Cs #28	20S	20	25S	25	60S	60	3	3^-
98	Cs #40	20S	20	30S	30	60S	60	3	3^-
99	Kakaba	5S-20S	14	33S	33	60S	60	3^-	3^-
100	Westonia	20S	20	90S	90	70S	70	3^+	3^-

Wheat lines with genetic background of SrB, Sr32, Sr45, Sr22, Sr21, Sr39, Sr33 and also wheat lines, which contain Lr67 in single and with unknown stem rust resistance genes were effective at seedling stage to stem rust TTKSK race with infection types less than 2^+($<2^+$). On the other hand wheat lines with genetic background of the following combinations: Sr24+Sr31+Sr50,Sr24+Sr31+Sr26,Sr24+Sr31,Sr24+Sr50,Sr50+Sr26,Sr50+Sr45, Sr33+Sr45,Sr33+Sr2 and Sr26+Sr31, were resistant to TTKSK stem rust race at the seedling stage. Additionally wheat lines with Yr5+18 was resistant to stem rust race TTKSK, this was probably due to having unknown seedling resistant gene to stem rust race TTKSK.

Wheat lines with resistant genes SrB, Sr32, Sr22, Sr45, Sr50, Sr21, SrAeslt, Sr21, Sr33 and Sr39 showed resistance to stem rust race TKTTF at seedling test in the greenhouse. In addition to the aforementioned single effective resistance genes, wheat lines that combine Sr24+Sr31+Sr50, Sr24+Sr26, Sr24+Sr26+Sr31, Sr24+Sr31, Sr24+Sr50, Sr50+Sr26, Sr50+Sr45, Sr50+Sr2, Sr33+Sr45, Sr33+Sr2, Sr26+Sr31 and Sr45+Sr2 were resistant to TKTTF stem rust race at seedling stage. In the same manner yellow rust resistant gene Yr15 and Yr5+18 were effective to stem rust race TKTTF at seedling stage.

Wheat lines with genetic background of SrB, Sr32, Sr45, Sr22, Sr21, Sr39, Sr33 in sole and wheat lines with genetic backgrounds of Sr24+Sr31+Sr50,Sr24+Sr31+Sr26, Sr24+Sr31, Sr24+Sr50,Sr50+Sr26, Sr50+Sr45, Sr33+Sr45,Sr33+Sr2, Sr26+Sr31 in combination were effective and resistant to both stem rust races TTKSK and TKTTF at seedling stage in greenhouse test with infection type values below 2^+($<2^+$IT).

Shorima and Ogolcho check wheat varieties had the lowest level of infection and were considered resistant to stem rust race TKTTF at the seedling stage. Contrarily wheat varieties Honqolo, Kingbird and Kekeba had maximum stem rust infection at seedling stage.

4.4.2. Leaf rust

The reaction of wheat lines to leaf rust infection was variable both under field and greenhouse conditions. Wheat line Pavon Sr 24+ SR 26+Sr 31 was free from leaf rust pustule for bulk isolates of leaf rust in Debrezeit (Figure 8). On the other hand, wheat line Av 36-29-34#20 was completely damaged by the disease.

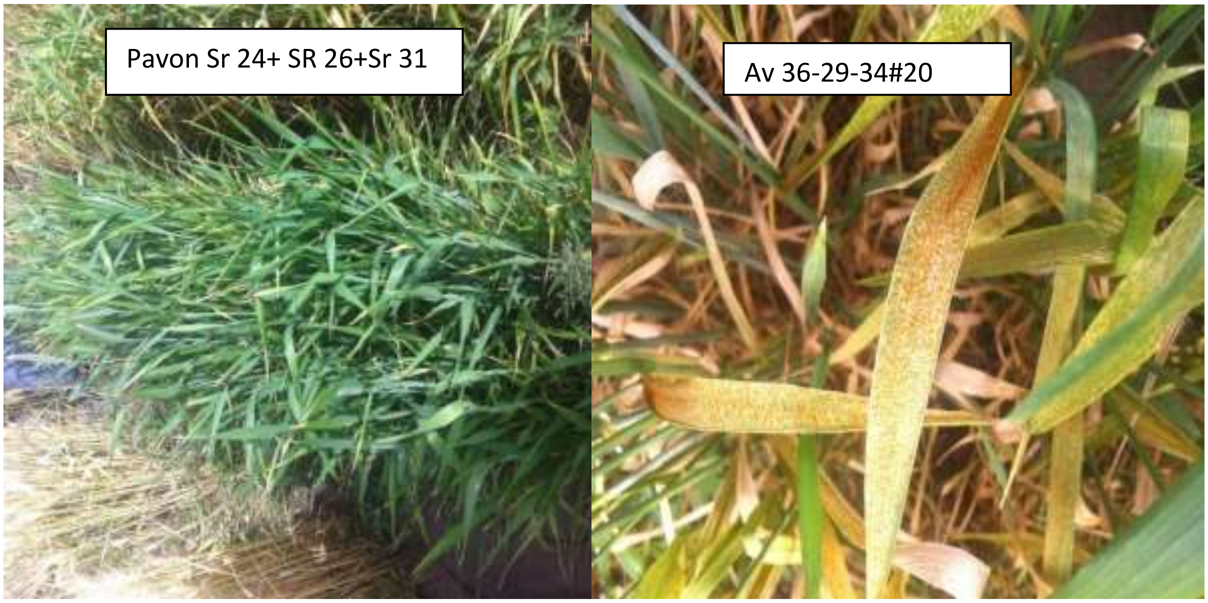

Figure 8. Leaf rust on two wheat varieties under field conditions of Debrezeit, 2015

Wheat lines Sr 33/Cs # 4, Sr 45/Cs #24, Sr 45+Sr 2/Cs# 32, CS # 42, Westonia Sr 50+ Sr 26 and Pavon Sr 24+ Sr 31+Sr 50 were found immune to leaf rust under field conditions across all the test areas (Table 9). Wheat lines with genetic background of Sr45/Cs, Sr45+Sr2/Cs, Sr33/Cs, Sr33+Sr2/Cs, Sr24+31+50, Sr24+31, Lr34, Sr24+50, Sr26+31 and Lr67,had minimum infection and hence could be considered resistant to leaf rust regardless of the test site.

Check varieties Shorima and Kingbird also had minimum infection while Danda'a, Ogolcho, Honqollo, Hidasse and Kekeba wheat varieties were with higher leaf rust coefficient of infection compared to the above mentioned checks.

Table 9. Responses of wheat lines to leaf rust

NO	Genotypes	Location: Debrezeit Severity	CI	Kulumsa Severity	CI	Seedling reaction: Arendeto	LAG672
1	Sr 33/Cs # 4	0	0	0	0	3	2
2	Sr 45/Cs #20	0	0	TRMR	1.6	3	2
3	Sr 45/Cs #24	0	0	0	0	2	2
4	Sr 45/Cs #25	0	0	TRMR	1.6	2	3
5	Sr 45+Sr 2/Cs# 32	0	0	0	0	3	3
6	CS # 42	0	0	0	0	4	4
7	Westonia Sr 50+ Sr 26	0	0	0	0	1	NG
8	Pavon Sr 24+ SR 26+Sr 31	0	0	5MR	2	1	1
9	Pavon Sr 24+ Sr 31+Sr 50	0	0	0	0	1	1
10	Shorima	0-TrMs	1	0	0	1	1
11	Sr 33/Cs #5	TMS	2.4	0	0	2	3
12	Sr 33+Sr 2/Cs #13	TMS	2.4	0	0	2	2
13	Sr 45/Cs #21	TMS	2.4	0	0	3	2
14	Sr 45+Sr 2/Cs #29	TMS	2.4	TRSMS	3	2	3
15	Sr 2/ Cs #19	TMS	2.4	0	0	4	3
16	Sr 2/ Cs # 51	TMS	2.4	TRS	3	3	4
17	Sr 2/ Cs # 52	TMS	2.4	0	0	3	3
18	Westonia Sr 24+ Sr 31	TMS	2.4	5MR	2	;	;
19	Quaiv	5MSS	4	TRR	0.8	3	2
20	Sr 33/Cs #1	5MS	4	0	0	3	3
21	Cs #39	5MSS	4	0	0	3	4
22	Cs # 41	5MS	4	0	0	4	4
23	Pavon Sr 24+ Sr 31	5MS	4	0	0	1	1
24	Sr 45/Cs #23	5S	5	5MSMR	3	2	3
25	Kingbird	8Ms	5	TRS	1	3	3

Note: *S= Susceptible MS= Moderately Susceptible MSS =Moderately susceptible and susceptible MR= Moderately resistance SMS=Susceptible and moderately susceptible MSMR=moderately susceptible moderately resistance*

Table 9. Continued

		Location					
		Debrezeit		Kulumsa		Seedling reaction	
NO	Genotypes	Severity	CI	Severity	CI	Arendeto	LAG672
26	Danda'a	5MsS-15Ms	7	0	0	3	3
27	Ogolcho	TrMs-30MsS	7	0-TrS	1	2	3
28	Sr 33+Sr 2/Cs #14	10MS	8	TrS	2	3	3
29	Sr 45+Sr 2/Cs# 20	10MS	8	TrMr	1.6	3	3
30	Sr 45+Sr 2/Cs# 33	10MSS	8	TrS	1	1	1
31	Sr 2/ Cs #48	10MSS	8	0	0	3	3
32	Sr 2+Cs 49	10MSS	8	TrS	4	3	3
33	Thatcher+Lr 34	10MS	8	10S	10	2	3
34	Honqolo	TrMs-20SMs	8	0	0	2	2
35	Cs #40	10SMS	10	TrS	2	4	3
36	Westonia Sr 24+ Sr 50	10SMS	10	0	0	1	;
37	Hidasse	0-20SMs	10	0	0	3	3
38	Sr 33+Sr 2/Cs #15	15MSS	12	0	0	3	3
39	Co 1 NS 765	15MSMR	12	0	0	3	1
40	Sr 33+Sr 2/Cs #12	15SMS	15	0	0	3	3
41	Kakaba	10Mss-30SMs	15	TrMr	1	3	3
42	Sr 33+Sr 2/Cs # 11	20MS	16	Trs	3	2	3
43	Sr 45+Cocamba	20MSS	16	TrMs	1.6	1	2
44	Westonia	20S	20	10s	10	2	3
45	Wes+S46 (B4)	20S	20	TrS	2	3	3
46	Sujata	20S	20	0	0	3	3
47	Sr 33/Cs # 2	20SMS	20	5S	5	2	3
48	Sr 33/Cs # 6	20SMS	20	0	0	2	3
49	Cs #28	20S	20	5S	5	3	3
50	Avocet	20S	20	40S	40	2	2

Table 9. Continued

		Location				Seedling reaction	
		Debrezeit		Kulumsa			
NO	Genotypes	Severity	CI	Severity	CI	Arendeto	LAG672
51	Pavon Sr 26+ SR 31	20S	20	5MSMR	3	1	;
52	C 591	30SMS	30	0	0	3	3
53	Sr 50+Sr 45 # 35	30S	30	10SMS	10	2	2
54	Sr 45+Sr 2/Cs #28	30S	30	TRS	2	1	2
55	Sr 21/kulin	30S	30	10MSS	8	2	2
56	Thatcher+Lr 67	30SMS	30	5MSMR	3	3	3
57	Sr 33+Sr 45 #4	40S	40	20SMS	20	2	2
58	Sr 45/Kulin	40S	40	5S	5	2	2
59	Kulin	40S	40	5MSMR	3	3	3
60	Sr 33+Sr 45 #23	40S	40	40S	40	2	3
61	Sr 50+Sr 45 # 10	40S	40	10SMS	10	1	3
62	Sr 50+Sr 45 # 33	40S	40	30S	30	2	3
63	Sr 50+Sr 45 # 37	40S	40	10MSMR	6	2	2
64	Westonia Sr 24+ Sr 26	40S	40	30SMS	30	2	2
65	Sr Aes1t	40S	40	0	0	1	2
66	Gato Sr 50	40S	40	10SMS	10	3	3
67	Sr 39	40S	40	TRMR	1.6	3	3
68	SA 8123(Sr B)	40S	40	15MSMR	9	3	2
69	Av Yr 15	50S	50	10SMS	10	2	2
70	WT6/12	50S	50	20SMS	20	3	3
71	Sr 33+45 # 9	50S	50	20SMS	20	3	3
72	Sr 33+Sr 45 #36	50S	50	10SMS	10	2	2
73	Sr 50+Sr 45 # 28	50S	50	15S	15	2	3
74	Sr 21+Cocamba	50S	50	10MSMR	6	2	2
75	CO1213	50S	50	20S	20	3	3

Table 9. Continued

NO	Genotypes	Location: Debrezeit Severity	CI	Kulumsa Severity	CI	Seedling reaction: Arendeto	LAG672
76	Thatcher	50S	50	10S	10	3	3
77	Thatcher+Lr 46	50S	50	5MS	4	4	4
78	Pavon Sr 24+ Sr 50	50S	50	10MS	8	2	2
79	CO1 NS 766	50S	50	5MSMR	3	2	1
80	Sr 33/WT 6/12	60S	60	20MSMR	12	3	2
81	LAG 672	60S	60	10MRMS	6	2	1
82	AvYr 5+18	60S	60	5SMS	5	2	3
83	Av 36-29-34# 10	60S	60	10MSMR	6	2	3
84	Sr 50+Sr 45 # 1	60S	60	5SMS	5	1	3
85	Sr 50+Sr 45 # 5	60S	60	10SMS	10	2	3
86	Sr 50+Sr 45 # 7	60S	60	10MSMR	6	2	3
87	Sr 50+Sr 45 # 27	60S	60	30S	30	2	2
88	Cocamba	60S	60	5MSMR	3	3	3
89	Avocet+Lr 67	60S	60	10SMS	10	4	2
90	AEG 91586 WHEA(westonia+ Sr B	60S	60	10S	20	2	1
91	Columbus	60S	60	20MSMR	12	3	3
92	ND Sr 1	60S	60	30SMS	30	2	3
93	Av 36-29-18#5	70S	70	5SMS	5	2	2
94	Wes+ S46(C5)	70S	70	15S	15	3	3
95	Sr 22/CO 1213	70S	70	30S	30	2	2
96	CANTHACHK	70S	70	10S	10	3	3
97	CT4-NS1	70S	70	15SMS	15	2	2
98	Angas Sr 32	70S	70	20MSMR	12	3	3
99	Av 36-29-34#20	80S	80	30S	30	1	2
100	CTH- Ns 2	80S	80	30MRMS	18	3	3

Note: *NG= Not germinated*

Wheat line Westonia Sr 50+ Sr 26, Pavon Sr 24+ SR 26+Sr 31, Pavon Sr 24+ Sr 31+Sr 50, Westonia Sr 24+ Sr 31, Pavon Sr 24+ Sr 31, Sr 45+Sr 2/Cs# 33, Westonia Sr 24+ Sr 50, Sr 45+Cocamba, Pavon Sr 26+ SR 31, Sr 45+Sr 2/Cs #28, Sr 50+Sr 45 # 10, Sr Aes1t, Sr 50+Sr 45 # 1 and Av 36-29-34#20 were resistant at field condition.

When tested in the greenhouse (seedling resistance) Westonia Sr 24+ Sr 31 was the only wheat line with very limited pustule and only fleck reaction to Arendeto isolate. On the other hand, wheat lines Pavon Sr 24+ SR 26+Sr 31, Pavon Sr 24+ Sr 31+Sr 50, Westonia Sr 24+ Sr 31, Pavon Sr 24+ Sr 31, Sr 45+Sr 2/Cs# 33, Westonia Sr 24+ Sr 50, Co 1 NS 765, Pavon Sr 26+ SR 31, CO1 NS 766, LAG 672 and AEG 91586 WHEA (westonia+ Sr B) were resistant to Lag672 isolate at seedling stage. Among resistant wheat lines to LAG672 isolate, wheat line Westonia Sr24+Sr31, Westonia Sr24+Sr50 and Pavon Sr26+Sr31 were proven highly resistant with fleck infection. Pavon Sr 24+ SR 26+Sr 31, Pavon Sr 24+ Sr 31+Sr 50, Westonia Sr 24+ Sr 31, Pavon Sr 24+ Sr 31, Sr 45+Sr 2/Cs# 33, Westonia Sr 24+ Sr 50 and Pavon Sr 26+ SR 31 were wheat lines which possessed resistance to both Arendeto and LAG672 isolates in greenhouse (at seedling stages).

Check variety Shorima was the only check which showed resistant to both leaf rust isolates in green house condition. The other check, Honqollo, had moderate /intermediate reaction to both isolates and Ogolcho check variety showed moderate infection type to Arendeto but was found susceptible to LAG672 isolate under green house condition. The rest check varieties, Hidasse, Danda'a, Kekeba and Kingbird were susceptible to both leaf rust isolates.

4.4.3. Yellow rust

During the course of this experiment, sever yellow rust was prevalent at Sinana Agricultural Research station as it is evident on the susceptible wheat cultivars Thatcher and westonia Sr24+Sr31 (Figure 9). This high disease pressure led to total failure of the aforementioned varieties (data not shown).

Figure 9. Yellow rust of wheat in Sinana (A and B), and Kulumsa (C), 2015

Wheat lines Av Yr 15, WT6/12, Sr 33/Cs # 4, Sr 33/Cs #5, Sr 33+Sr 2/Cs #14, Sr 33+Sr 2/Cs #15, Sr 45/Cs #20 and Sr 45+Sr 2/Cs #29 were immune at field condition of all locations (Table 10). However, Westonia, Thatcher, Avocet, CANTHACHK, CT4-NS1, Pavon Sr 26+ SR 31, Westonia Sr 24+ Sr 31, Pavon Sr 24+ Sr 31 and CTH- Ns 2 exhibited maximum field severity and coefficient of infection both at Kulumsa and Sinana field conditions.

Among the tested check varieties, all except one were good against yellow rust in both locations, having minimum coefficient of infection. The susceptible check variety Avocet, on the other hand, had the maximum field severity at both locations.

Table 10. Responses of wheat lines to yellow rust, 2015

		Location					
		Sinana		Kulumsa		Seedling response(IT)	
NO	Genotypes	Severity	CI	Severity	CI	Kubsa isolate	Digelu isolate
1	Sujata	0	0	5MR	2	5	4
2	C 591	0	0	10MR	4	7	6
3	Av Yr 15	0	0	0	0	1	0
4	Av 36-29-34#20	0	0	TRMR	1.6	9	5
5	WT6/12	0	0	0	0	7	5
6	Sr 33/WT 6/12	0	0	5MR	2	7	4
7	Sr 50+Sr 45 # 35	0	0	10S	10	7	5
8	Sr 33/Cs # 4	0	0	0	0	7	7
9	Sr 33/Cs #5	0	0	0	0	7	6
10	Sr 33+Sr 2/Cs #14	0	0	0	0	6	7
11	Sr 33+Sr 2/Cs #15	0	0	0	0	4	6
12	Sr 45/Cs #20	0	0	0	0	7	6
13	Sr 45/Cs #21	0	0	TRS	1	6	5
14	Sr 45/Cs #25	0	0	TRMR	1.6	6	6
15	Sr 45/Cs #23	0	0	TRS	1	8	1
16	Sr 45+Sr 2/Cs #29	0	0	0	0	6	3
17	Sr 45+Sr 2/Cs# 32	0	0	TRS	1	6	7
18	Sr 2/ Cs # 52	0	0	TRMR	1.6	7	5
19	Cs #39	0	0	10S	10	6	7
20	Cs #40	0	0	5SMS	5	7	6
21	CS # 42	0	0	TRS	1	6	4
23	Av 36-29-18#5	TRMS	2.4	0	0	9	9
24	Sr 33+Sr 45 #36	TRMS	2.4	5S	5	9	8
25	AvYr 5+18	TRMS	2.4	10MR	4	1	1

Note: *S= Susceptible MS= Moderately Susceptible MSS = Moderately susceptible and susceptible MR= Moderately resistance SMS=Susceptible and moderately susceptible MSMR=moderately susceptible moderately resistance*

CI=Coefficient of infection

Table 10. Continued

NO	Genotypes	Location: Sinana Severity	CI	Kulumsa Severity	CI	Seedling response(IT) Kubsa isolate	Digelu isolate
26	Av 36-29-34# 10	TRMS	2.4	10S	10	9	7
27	Sr 33+Sr 2/Cs #13	TRMS	2.4	0	0	7	4
28	Sr 45/Cs #24	TRMS	2.4	TRS	2	7	6
29	Sr 2/ Cs #19	TRMS	2.4	TRS	1	7	8
30	Sr 2/ Cs # 51	TRMS	2.4	TRS	1	9	8
31	Sr 2/ Cs #48	TRMS	2.4	TRMS	3.2	5	6
32	Sr 2+Cs 49	TRMS	2.4	TRMS	3.2	7	7
33	Cs #28	TRMS	2.4	5MS	3.2	6	7
34	Cs # 41	TRMS	2.4	5MS	4	6	7
35	Kingbird	TRMS-5S	4	0-5S	2	9	7
36	Quaiv	5MS	4	0	0	9	9
37	Sr 33+Sr 45 #23	5MS	4	TRS	1	9	8
38	Sr 33/Cs # 2	5MS	4	TRS	2	6	5
39	Sr 33/Cs # 6	5MS	4	0	0	8	6
40	Sr 33+Sr 2/Cs # 11	5MS	4	0	0	1	1
41	Sr 45+Sr 2/Cs# 20	5MS	4	0	0	5	6
42	Sr 45+Sr 2/Cs# 33	5MS	4	TRS	1	5	6
43	Honqolo	TRMS-10S	5	0-TRS	0	8	7
44	Sr 33+Sr 2/Cs #12	5S	5	0	0	5	7
45	Danda'a	8MS	6	0	0	7	8
46	Sr 33/Cs #1	10MS	8	TRS	1	6	3
47	Thatcher+Lr 34	10MSS	8	5S	5	9	8
48	Pavon Sr 24+ SR 26+Sr 31	10MS	8	0	0	0	5
49	Angas Sr 32	10MS	8	0	0	2	0
50	Ogolcho	10MS	8	0-20S	10	6	4

Table 10. Continued

		Location					
		Sinana		Kulumsa		Seedling response(IT)	
NO	Genotypes	Severity	CI	Severity	CI	Kubsa isolate	Digelu isolate
51	Sr 33+45 # 9	10S	10	5MSMR	3	9	7
52	Sr 50+Sr 45 # 1	10S	10	10SMS	10	8	6
53	Sr 50+Sr 45 # 27	10S	10	10S	10	9	7
54	Sr 50+Sr 45 # 33	10S	10	20S	20	8	6
55	Sr 50+Sr 45 # 37	10MS	10	5S	5	7	5
56	Westonia Sr 50+ Sr 26	10S	10	10S	10	9	9
57	Shorima	5MS-20S	11	TRS	1	7	5
58	Sr 50+Sr 45 # 28	15MS	12	20S	20	1	6
59	Hidasse	10MS-20S	15	0-5MS	2	7	5
60	Sr 33+Sr 45 #4	20S	20	15S	15	9	8
61	Sr 50+Sr 45 # 10	20S	20	20S	20	9	5
62	Sr 45+Sr 2/Cs #28	20S	20	TRS	1	8	8
63	Kakaba	10MS-50S	23	0-TRS	1	9	8
64	LAG 672	30S	30	10S	10	8	8
65	Sr 50+Sr 45 # 5	30S	30	15S	15	7	6
66	Sr 50+Sr 45 # 7	30S	30	5S	5	9	8
67	Thatcher+Lr 67	30S	30	10S	10	9	8
68	Westonia Sr 24+ Sr 50	30S	30	5SMS	5	9	9
69	Westonia Sr 24+ Sr 26	30S	30	0	0	9	9
70	Kulin	40S	40	5S	5	9	9
71	Sr 45/Kulin	50S	50	5S	5	9	9
72	Sr 45+Cocamba	50S	50	TRMS	3.2	9	8
73	Cocamba	50S	50	0	0	9	8
74	Sr 21+Cocamba	60S	60	TRMR	1.6	9	8
75	Sr 22/CO 1213	60S	60	10S	10	9	9

Table 10. Continued

		Location				Seedling response(IT)	
		Sinana		Kulumsa			
NO	Genotypes	Severity	CI	Severity	CI	Kubsa isolate	Digelu isolate
76	CO1213	60S	60	10S	10	9	9
77	Avocet+Lr 67	60S	60	5S	5	9	7
78	SA 8123(Sr B)	60S	60	0	0	9	9
79	Wes+S46 (B4)	70S	70	15S	15	9	7
80	Wes+ S46(C5)	70S	70	5S	5	9	9
81	Pavon Sr 24+ Sr 50	70S	70	20S	20	9	8
82	Sr Aes1t	70S	70	5S	5	9	7
83	AEG 91586 WHEA(westonia+ Sr B	70S	70	15S	15	9	7
84	CO1 NS 766	70S	70	10S	10	9	6
85	Sr 21/kulin	80S	80	5S	5	9	8
86	Thatcher+Lr 46	80S	80	15S	15	8	9
87	Pavon Sr 24+ Sr 31+Sr 50	80S	80	15S	15	9	9
88	Gato Sr 50	80S	80	15S	15	9	9
89	Co 1 NS 765	80S	80	15S	15	9	8
90	Columbus	80S	80	20S	20	9	7
91	ND Sr 1	80S	80	15S	15	9	8
92	Westonia	90S	90	60S	60	8	8
93	Thatcher	90S	90	15S	15	9	9
94	Avocet	90S	90	40S	40	9	9
95	CANTHACHK	90S	90	10S	10	9	9
96	CT4-NS1	90S	90	15S	15	9	7
97	Pavon Sr 26+ SR 31	90S	90	5S	5	9	9
98	Westonia Sr 24+ Sr 31	90S	90	10S	10	8	9
99	Pavon Sr 24+ Sr 31	90S	90	50S	50	9	8
100	CTH- Ns 2	90S	90	10S	10	9	9

When tested under greenhouse condition for seedling resistance against Kubsa and Digalu isolates of yellow rust, wheat lines Av Yr 15, AvYr 5+18, Sr 33+Sr 2/Cs # 11, Pavon Sr 24+ SR 26+Sr 31, Angas Sr 32 and Sr 50+Sr 45 # 28 were found to have lower level of infection by yellow rust and hence considered as relatively resistant to the disease. Wheat lines Pavon

Sr 24+ Sr 31+Sr 50, Gato Sr 50, Co 1 NS 765, Columbus, ND Sr 1, Westonia, Thatcher, CANTHACHK, CT4-NS1, Avocet, Pavon Sr 26+ SR 31, Westonia Sr 24+ Sr 31, Pavon Sr 24+ Sr 31 and CTH- Ns 2 had higher disease level as it was evident from the infection types.

In a similar manner wheat lines Av Yr 15, AvYr 5+18, Sr 45/Cs #23, Sr 33+Sr 2/Cs # 11, Sr 33/Cs #1, Angas Sr 32 and Sujata were found resistant to only one of the two isolates, Digelu isolate. Check variety Ogolcho was the only variety which had low infection type to both Kubsa and Digelu isolates. Shorima and Hidasse exhibited resistance or low infection types to Digelu isolate but both of them were susceptible to to Kubsa isolate. The rest of check varieties had maximum/ highest infection types at seedling stage to both yellow rust isolates. The susceptible avoecet check variety also exhibited highest infection type in green house.

4.4.4. Field and seedling reaction of wheat lines to triple rusts

Testing wheat lines to triple rusts is crucial at a time to have concrete data regarding resistant to all rust types both at adult and seedling stage to identify the effective materials to all rusts. Based on the current finding wheat lines resistant to all rust types at the field and at seedling stage were noted. Wheat lines Sr 50+Sr 45 # 35, Sr 45/Cs #20, Sr 45/Cs #21, Sr 45/Cs #25, Sr 45+Sr 2/Cs #29, Sr 45+Sr 2/Cs# 20, Sr 45+Sr 2/Cs# 33, Sr 45+Sr 2/Cs# 32, Thatcher+Lr 34, Westonia Sr 50+ Sr 26, Westonia Sr 24+ Sr 50 and Pavon Sr 24+ SR 26+Sr 31 were resistant at field conditions of all tested locations for triple rusts (Table 8, 9 & 10). The only resistant wheat line to the combination of rusts at all fields and at greenhouse to all isolates of leaf rust and yellow rust was Pavon Sr24+Sr26+Sr31 and it was also resistant to TTKSK and TKTTF stem rust races in green house at seedling stage under controlled environment. Wheat lines with genetic background of *Sr2* APR either sole or in combination with *Sr45* stem rust resistance genes were resistance to triple rusts except to TTKSK races at seedling stage due to possession of *Yr30* linked to yellow rust resistance gene and with unknown leaf rust resistance gene.

Most wheat lines tested at Kulumsa against triple rusts had lower level of infection by triple rust this may be as a result of unusual weather condition at Kulumsa as indicated in Appendix tables 7,8 & 9. About 21 and 72 wheat lines showed lower infection to stem rust races (TTKSK and TKTTF, respectively) at seedling stage. About 3 and 15 wheat lines showed lower infection type by yellow rust isolates, Digelu and Kubsa, respectively. Besides, 15 and 14 wheat lines showed lower infection at seedling stage by Arendeto and LAG672 isolates of leaf rust, respectively (Table 11).

Table 11. Responses of wheat lines against triple rusts at Kulumsa (Set-II), 2015

		Field response of wheat lines lines						Seedling reaction of wheat					
		Yellow rust		Stem rust		Leaf rust		**Yellow rust isolate**		**Leaf rust isolate**		**Stem rust race**	
No	Genotypes	Severity (%)	CI	Severity (%)	CI	Severity (%)	CI	Kubsa Isolate	Digelu Isolate	Arendeto isolate	Lag 672 isolate	TTKSK	TKTTF
1	HUBARA-13/MOONTASIR-3	0	0	0	0	5MR	2	8	6	3	3	3^-	2^+
2	TEVEE'S'/BOBWHITE #1//ASEEL-1	5S	5	5MR	2	0	0	9	7	2	3	3^-	1
3	TEVEE'S'/BOBWHITE #1//ASEEL-1	0	0	5MR	2	10MSMR	6	7	8	2	3	3^-	1^+
4	VEE#5/SARA//DUCULA/3/NJORO SD-7	0	0	5MR	2	5MSMR	3	9	7	1	1	2	1^+
5	BAOBAB-1//MILAN/PASTOR	0	0	5MR	2	0	0	9	9	2	3	3^-	1^+
6	HUBARA-1/ETBW 4921	0	0	5MR	2	0	0	7	1	3	3	3^-	2^-
7	MILAN/PASTOR//FLAG-5	0	0	5MR	2	0	0	7	8	3	2	2^+	1^+
8	SOMAMA-9/ETBW 4921	0	0	5MR	2	0	0	8	1	1	1	1^+	1^+
9	PASTOR/3/VEE#5//DOVE/BUC/4/ETBW 4919	0	0	5MR	2	0	0	9	9	1	2	3^-	2^-
10	SERI*3//RL6010/4*YR/3/PASTOR/4/BAV92/5/ETBW 4921	0	0	5MR	2	0	0	9	9	2	3	1	3^-
11	DEBEIRA	0	0	TRMSMR	4	TRS	4	9	9	3	3	3^-	3^-
12	OPATA/RAYON//KAUZ/3/MILAN/DUCULA	0	0	5MRMS	3	0	0	9	0	3	3	3^-	2^-
13	Sids-12	TrS	2	5MSMR	3	0	0	6	7	3	3	3	2
14	BACANORA T 88/RUTH-2	0	0	5MRMS	3	0	0	8	8	3	3	3^-	2^-
15	BACANORA T 88/RUTH-2	0	0	5MRMS	3	0	0	9	9	3	3	3^-	2
16	HUBARA-5/EALME4SA -167	0	0	5MSMR	3	0	0	7	6	1	2	1^+	3^-
17	BOW/PRL//BUC/3/WH576/4/N-AZRAQ-2	0	0	10Mr	4	0	0	8	6	3	3	3^-	3^-
18	SERI.1B//KAUZ/HEVO/3/AMAD/4/ESWYT99#18/ARRIHANE	0	0	10Mr	4	0	0	9	7	3	3	3	2
19	HUBARA-13/MOONTASIR-3	0	0	10MR	4	15MSMR	9	6	7	3	3	3^-	3^-
20	SERI.1B//KAUZ/HEVO/3/AMAD/4/MILAN/PASTOR	0	0	5MS	4	0	0	1	7	3	4	3^-	2

Note: *S= Susceptible MS= Moderately Susceptible MSS = Moderately susceptible and susceptible MR= Moderately resistance SMS=Susceptible and moderately susceptible MSMR=moderately susceptible moderately resistance*

Table 11 .Continued

		Field response of wheat lines						Seedling reaction of wheat lines					
		Yellow rust		Stem rust		Leaf rust		**Yellow rust isolate**		**Leaf rust isolate**		**Stem rust race**	
No	Genotypes	severity (%)	CI	Severity (%)	CI	severity (%)	CI	Kubsa Isolate	Digelu Isolate	Arendeto isolate	Lag 672 isolate	TTKSK	TKTTF
21	HUITES/4/CS/TH.SC//3*PVN/3/MIRLO/BUC/5/MOONTSIR-3	0	0	10MR	4	5MS	4	9	7	3	3	3^{-}	2^{-}
22	DEBEIRA	0	0	10MR	4	TRS	2	9	9	3	3	3^{-}	1^{-}
23	HUBARA-5/ETBW 4922	0	0	10MR	4	5MR	2	8	9	3	3	1	1
24	OPATA/RAYON//KAUZ/3/ACHTAR/INRA 1764	0	0	10MR	4	0	0	9	7	3	3	3^{-}	1
25	HAMAM-4/FAISAL-1	5S	5	5MS	4	5S	5	8	9	3	3	2^{+}	1^{+}
26	KBG-01//MILAN/PASTOR	15S	15	10MR	4	0	0	9	9	1	3	1	1^{+}
27	TEVEE'S'/BOBWHITE #1//ASEEL-1	TrMR	1.6	5SMS	5	TRMS	1.6	9	9	3	3	3^{-}	1
28	WATAN-6//SKAUZ/2*STAR	0	0	5S	5	0	0	9	8	3	3	3^{-}	3^{-}
29	WATAN-6//SKAUZ/2*STAR	TrMR	1.6	5S	5	0	0	7	4	4	2	3^{-}	1^{+}
30	HUBARA-1/5/KAUZ/3/MYNA/VUL//BUC/FLK/4/MILAN	0	0	5S	5	20MSMR	12	9	6	3	3	3^{-}	2^{+}
31	JAWAHIR-6/QAMAR-5	0	0	5SMS	5	5S	5	9	9	3	4	3^{-}	1^{+}
32	ALMAZ-8/FLAG-4	0	0	5S	5	0	0	7	0	3	3	2^{+}	1^{+}
33	CHAM-6/SHUHA-14//ETBW 4921	0	0	5SMS	5	5MR	2	8	8	;	2	3^{-}	2^{+}
34	CHAM-6/SHUHA-14//ETBW 4921	5s	5	5S	5	0	0	9	9	3	2	2^{+}	3^{-}
35	LFN/II58.57//PRL/3/HAHN/4/KAUZ/5/KAUZ/6/ETBW 4920	0	0	5SMS	5	5MSMR	3	7	1	3	3	3^{-}	3^{-}
36	DEBEIRA//SHUHA-8/DUCULA	0	0	10MSMR	6	0	0	9	9	3	3	3^{-}	3^{-}
37	Attila-7	0	0	10MSMR	6	TRS	3	9	9	3	3	3^{-}	3^{-}
38	PFAU/MILAN//MOONTASIR-3	0	0	10MSMR	6	0	0	9	9	3	3	3^{-}	2^{-}
39	DAJAJ-5/4/CHEN/AEGILOPS SQUARROSA (TAUS)//BCN/3/KAUZ	0	0	10MSMR	6	10SMS	10	9	7	3	3	3^{-}	1^{+}
40	ALMAZ-8/FLAG-4	5S	5	10MSMR	6	5MR	2	9	9	3	3	3^{-}	2

Table 11 .Continued

		Field response of wheat lines						Seedling reaction of wheat lines					
		Yellow rust		Stem rust		Leaf rust		**Yellow rust isolate**		**Leaf rust isolate**		**Stem rust race**	
No	Genotypes	Severity (%)	CI	Severity (%)	CI	Severity (%)	CI	Kubsa Isolate	Digelu Isolate	Arendeto isolate	Lag 672 isolate	TTKSK	TKTTF
41	ALMAZ-8/FLAG-4	5S	5	10MSMR	6	10SMS	10	8	9	3	2	3^{-}	2
42	KBG-1	0	0	10MSMR	6	0	0	7	8	3	3	3^{-}	2^{-}
43	BACANORA T 88/RUTH-2	0	0	10MSMR	6	5MR	2	9	9	3	3	3^{-}	1^{+}
44	TEVEE'S'/BOBWHITE #1//ASEEL-1	0	0	10MSMR	6	0	0	9	8	2	3	3^{-}	2^{+}
45	DEZ/ETBW 4919	0	0	10MSMR	6	0	0	9	8	3	3	3^{-}	2^{+}
46	LFN/II58.57//PRL/3/HAHN/4/KAUZ/5/KAUZ/6/ETBW 4920	0	0	10MSMR	6	5MR	2	7	3	3	3	2^{+}	3^{-}
47	RABIH-10/ETBW 4922	10S	10	10MSMR	6	0	0	7	7	3	3	2^{+}	2^{+}
48	BAOBAB-1//MILAN/PASTOR	0	0	10MSMR	6	15MSMR	9	8	5	3	3	2^{+}	2
49	HUBARA-1/ETBW 4921	0	0	10MSMR	6	0	0	7	8	4	3	3^{-}	2^{+}
50	PASTOR/3/VEE#5//DOVE/BUC/4/ETBW 4919	TrS	3	15MR	6	0	0	9	9	2	2	1^{+}	2^{+}
51	DEBEIRA//SHUHA-8/DUCULA	0	0	10MS	8	20SMS	20	9	9	3	4	3^{-}	2
52	PFAU/MILAN//MOONTASIR-3	0	0	10MS	8	0	0	9	9	3	3	2^{+}	2^{-}
53	DAJAJ-5/4/CHEN/AEGILOPS SQUARROSA (TAUS)//BCN/3/KAUZ	TrS	3	10MS	8	5S	5	9	9	3	3	3^{-}	1^{+}
54	HADIAH-14/QAMAR-1	0	0	10MSS	8	10SMS	10	9	8	1	1	1^{+}	1^{+}
55	HAMAM-4/FAISAL-1	10S	10	10MS	8	5S	5	9	9	3	4	3^{-}	1^{+}
56	SERI.1B//KAUZ/HEVO/3/AMAD/4/ESWYT99#18/ARRIHANE	0	0	15MSMR	9	0	0	9	8	3	3	3^{-}	2
57	LFN/II58.57//PRL/3/HAHN/4/KAUZ/5/KAUZ/6/ETBW 4920	0	0	15MSMR	9	0	0	8	8	3	3	$3^{=}$	3^{-}
58	GOUMRIA-3/ETBW 4920	0	0	15MSMR	9	10MSMR	6	8	8	3	3	3^{-}	2
59	Sids-12	5S	5	10SMS	10	5S	5	8	8	3	3	3^{-}	2^{+}
60	PFAU/MILAN//MOONTASIR-3	0	0	10SMS	10	0	0	8	8	3	2	3^{-}	2^{+}

Table 11. Continued

		Field response of wheat lines						Seedling reaction of wheat lines					
		Yellow rust		Stem rust		Leaf rust		**Yellow rust Isolate**		**Leaf rust isolate**		**Stem rust race**	
No	Genotypes	Severity (%)	CI	Severity (%)	CI	Severity (%)	CI	Kubsa Isolate	Digelu Isolate	Arendeto isolate	Lag 672 isolate	TTKSK	TKTTF
61	DAJAJ-5/4/CHEN/AEGILOPS SQUARROSA (TAUS)//BCN/3/KAUZ	10S	10	10SMS	10	15S	15	9	9	3	3	3^-	1^+
62	DAJAJ-5/4/CHEN/AEGILOPS SQUARROSA (TAUS)//BCN/3/KAUZ	0	0	10S	10	20SMS	20	9	8	4	2	3^-	2^+
63	HUBARA-1/5/KAUZ/3/MYNA/VUL//BUC/FLK/4/MILAN	5S	5	10SMS	10	10S	10	9	9	3	3	2^+	2^-
64	ALMAZ-19/ZEMAMRA-8	5S	5	10SMS	10	0	0	8	9	2	3	2	3^-
65	DEZ/ETBW 4919	0	0	10S	10	0	0	8	7	3	3	3	2^+
66	LFN/II58.57//PRL/3/HAHN/4/KAUZ/5/KAUZ/6/ETBW 4920	0	0	10SMS	10	TRS	2	8	8	3	3	2^+	2^+
67	SERI*3//RL6010/4*YR/3/PASTOR/4/BAV92/5/ETBW 4921	0	0	10SMS	10	5S	5	9	9	3	3	3^-	3^-
68	PFAU/MILAN//JAWAHIR-9	TrS	1	15S	15	0	0	9	9	2	3	3^-	2^+
69	WATAN-6//SKAUZ/2*STAR	0	0	15S	15	10SMS	10	8	5	4	4	3^-	2^-
70	DEBEIRA//SHUHA-8/DUCULA	0	0	15S	15	20S	20	9	9	3	3	3^-	3^+
71	DAJAJ-5/4/CHEN/AEGILOPS SQUARROSA (TAUS)//BCN/3/KAUZ	0	0	15SMS	15	10MR	4	9	9	2	4	3^-	2
72	HUBARA-1/5/KAUZ/3/MYNA/VUL//BUC/FLK/4/MILAN	0	0	15SMS	15	0	0	9	8	3	3	3	2^-
73	SOSSI-7//MILAN/PASTOR	0	0	15S	15	5MSMR	3	9	9	3	4	3	3
74	JAWAHIR-6/QAMAR-5	5s	5	15SMS	15	15MSMR	9	8	8	3	3	3^-	2^-
75	ZAIEM-4/5/JUN//MAYA/MON/3/PGO/4/MILAN	5S	5	15SMS	15	15MS	12	7	8	3	3	3^-	2^+
76	SERI.1B//KAUZ/HEVO/3/AMAD/4/MILAN/PASTOR	TrS	3	15SMS	15	5S	5	8	7	3	4	3^-	3^-
77	LFN/II58.57//PRL/3/HAHN/4/KAUZ/5/KAUZ/6/ETBW 4920	0	0	15SMS	15	5MSMR	3	9	7	3	3	2^+	3^-
78	BOW/PRL//BUC/3/WH576/4/ETBW 4919	0	0	15SMS	15	0	0	9	9	3	4	3^-	1^+
79	ALMAZ-15/SOMAMA-3	10s	10	20MS	16	10SMS	10	9	9	3	3	3^-	2^+
80	WATAN-6//SKAUZ/2*STAR	10Mrms	6	20SMS	20	5MR	2	6	7	3	3	3^-	2^+

Table 11. Continued

		Field response of wheat lines						Seedling reaction of wheat lines					
		Yellow rust		Stem rust		Leaf rust		**Yellow rust isolate**		**Leaf rust isolate**		**Stame rust race**	
No	Genotypes	Severity (%)	CI	Severity (%)	CI	Severity (%)	CI	Kubsa Isolate	Digelu Isolate	Arendeto isolate	Lag 672 isolate	TTKSK	TKTTF
81	WATAN-6//SKAUZ/2*STAR	0	0	20SMS	20	0	0	9	8	2	3	3^-	2^+
82	DEBEIRA//SHUHA-8/DUCULA	0	0	20S	20	15MSMR	9	9	9	3	3	3^-	3^+
83	DAJAJ-5/4/CHEN/AEGILOPS SQUARROSA (TAUS)//BCN/3/KAUZ	0	0	20S	20	20S	20	7	7	3	3	3^-	2
84	HUBARA-1/5/KAUZ/3/MYNA/VUL//BUC/FLK/4/MILAN	0	0	20S	20	0	0	9	9	3	3	3^-	3^-
85	HUBARA-1/5/KAUZ/3/MYNA/VUL//BUC/FLK/4/MILAN	TrS	3	20SMS	20	TRMSMR	2.4	8	8	3	3	3^-	1^+
86	TEVEE-1/SD 8036//MOONTASIR-2	0	0	20S	20	0	0	9	9	3	3	2^+	1^+
87	SOSSI-7//MILAN/PASTOR	0	0	20SMS	20	0	0	8	9	3	4	3	1^+
88	JAWAHIR-8/ZEMAMRA-8	5S	5	20SMS	20	15MRMS	9	6	9	3	3	3^-	3^-
89	ZAIEM-4/5/JUN//MAYA/MON/3/PGO/4/MILAN	TrS	2	20S	20	0	0	8	8	3	4	3^-	2^-
90	ALMAZ-15/SOMAMA-3	TrS	3	20S	20	20MSS	16	9	9	3	3	3^-	1^+
91	CHAM-8/RUTH-3	0	0	20SMS	20	10MSMR	6	9	9	3	3	3^-	3^-
92	ALMAZ-11/3/PASTOR/FLORKWA-1//PASTOR	5S	5	20SMS	20	30SMS	30	9	9	3	3	3^-	2^-
93	PFAU/MILAN//ETBW 4921	0	0	20S	20	15MSMR	9	8	5	3	2	3^-	1^-
94	HUBARA-1/ETBW 4921	0	0	20SMS	20	5MSMR	3	6	0	3	3	3^-	3^-
95	GOUMRIA'S'/NJORO SD-7	0	0	30SMS	30	5S	5	8	8	3	3	3	2^-

5. DISCUSSION

In Ethiopia, several wheat cultivars have been released since the inception of wheat breeding in the 1950s. However, most of those cultivars were abandoned from production due to their susceptibility to diseases especially the cereal rusts, yellow rust (*Puccinia striiformis* Westend.) and stem rust (*Puccinia graminis f.sp. tritici*) (Ayele Badebo, 2002). Screening wheat lines against triple rusts both at field and greenhouse, and inventory of the resistance genes in the current wheat cultivars and searching for new sources of resistance are amongst the major objectives of successful wheat improvement program.

Currently most of wheat varieties produced in wheat belt areas of the country are wiped out due to rusts within a short period of time. Such a problem has occurred due to development of virulent races of major rusts in Ethiopia. The most distructive rust types are stem and yellow rusts, which threaten wheat production in the country and cause considerable yield losses, sometimes even crop failures. Screening or developing wheat lines against specific (single) rust type does not guarantee better yield or diseases resistance in any cropping season as wheat rusts often occur in combination than in isolation. As a result screening and evaluating wheat lines to triple rusts should be given due attention to minimize the loss of wheat yields and feed the ever increasing population of the world. In view of the above facts, field and greenhouse experiments were conducted in three rust hot beds, namely: Kulumsa, Sinana and Debrezeit.

The current experiment in Southeastern and Central Ethiopia indicated that among tested stem rust differential hosts, virulence race to *Sr22* and *Sr30* were not detected at Sinana. At Kulumsa virulences were not detected to *Sr22* and *Sr17*. But, at Debrezeit virulences were detected to all differential hosts tested at field condition. A stem rust differential with resistant gene SrTmp was susceptible at all locations and the current result is contradicting with the finding of Endale Hailu *et al*. (2015) who reported that SrTmp resistant gene is effective to stem rust. In other case all, leaf rust differentials tested in the study areas were affected by the disease but the differential line Gaza having *Lr23* was immune at field condition of Kulumsa which indicates the absence of virulence race to *Lr23* in that specific place. Yellow rust differentials were also planted at Sinana and Kulumsa and the field response of differential lines revealed that only virulence race to *Yr15* was not detected at both locations. Additionally virulence races to *YR5*, *YR8*, *YR15, YR17, YR27*, AVOCET S, Lassik (-*Yr5*) and Lassik (+Yr5) differentials were also not detected at Kulumsa field condition. In contrary yellow rust races virulent to *Yr1*, *Yr6*, *Yr7*, *Yr9* and *Yr18* was detected at Kulumsa field condition and this result agreed with the finding of Worku Denbel (2014).

Of wheat lines tested at field condition, those with the genetic background of *Sr45*, *Sr50* in sole and in different combination were found to be effective against the prevailing stem rust races in all study areas and the current results are inline with the findings of Jin & Singh (2006). Wheat lines with genetic background of resistant genes *Sr21* and *Sr32* were proven resistant in the present study and that Alemayehu Hailu (*et al*., 2015). Wheat lines with genetic background of resistant gene *Sr24* in different combination were found to be effective to both TTKSK and TKTTF stem rust races at seedling stage in greenhouse condition agreeing with the findings of Endale Hailu *et al*. (2015); Teklay Abebe *et al*. (2012); Abiyot Lemma *et al*. (2015) and Alemayehu Hailu *et al*. (2015).

Yr15, *Yr5* yellow rust resistance genes were found to be effective both at field and green house conditions and the current results are in agreement with (Sharma-Poudyal *et al*.,2013;Worku Denbel, 2014). In the same manner, wheat line with seedling resistance gene *YrSuj* also showed resistance to stripe/yellow rust both at field and greenhouse condition. This confirmed the findings of Lan *et al*. (2015).

Avocet showed resistance to leaf rust at field and greenhouse condition and this might be due to the possession of race specific *lr13* resistance gene (Riaz *et al*., 2016). Wheat lines developed with *Lr34* genetic background also showed moderately resistance reaction at field condition of Deberezeit despite the heavy pressure of leaf rust. This confirmed the effectiveness of *Lr34* (Abdelbacki *et al*., 2013). Nonetheless, the resistance gene *Lr46* was not effective at Debrezeit condition and the result was contrary to the findings of Imbaby *et al*. (2014). The resistance genes *Lr9* and *Lr2a* were not effective at field conditions of Kulumsa, Debrezeit and Sinana which is also in disagreement with the report by Tesfaye Gebrekirstos *et al*. (2016). In addition, host differentials with resistance genes *Lr3*, *Lr18*, *Lr10* and *LrB* were not effective at across the three locations. Tesfaye Gebrekirstos *et al*. (2016) also reported similar results in previous studies.

Wheat lines Sr 50+Sr 45 # 35, Sr 45/Cs #20, Sr 45/Cs #21, Sr 45/Cs #25, Sr 45+Sr 2/Cs #28, Sr 45+Sr 2/Cs #29, Sr 45+Sr 2/Cs# 20, Sr 45+Sr 2/Cs# 33, Sr 45+Sr 2/Cs# 32, Thatcher+Lr 34, Westonia Sr 50+ Sr 26, Westonia Sr 24+ Sr 50 and Pavon Sr 24+ SR 26+Sr 31 were resistant at field conditions of all tested locations against triple rusts due to possession of additional resistant genes and these results were in agreement with Roelfs *et al*. (1985). The same also holds true for wheat line with genetic background of *Lr34*, which was also resistant to the triple rusts at field conditions and this finding agreed with that Spielmeyer *et al*. (2013).

6. SUMMARY AND CONCLUSION

Wheat rusts (yellow, leaf and stem rust) caused by *Puccinia* spp., are major devastating fungal diseases world wide including in Ethiopia. Yellow and stem rust may cause grain yield losses of 100% and leaf rust causes grain yield of 75% in susceptible common wheat cultivars during diseases epidemics. Despite frequent occurance of yellow and stem rusts, and also occasional prevalence of leaf rust, there have not been enough study concerning triple rust resistance. In additiona, the genetic makeups of the resistant varieties were not clearly identified and stated. In the present study resistant wheat lines and effective genes were evaluated and identified in the context of wheat breeding to overcome the triple rust problem in Ethiopia. The major findings are outlined as follows.

Pavon Sr 24+ Sr 31+Sr 50, Angas Sr 32, Westonia Sr 50+ Sr 26, Pavon Sr 24+ SR 26+Sr 31, Gato Sr 50, Sr 50+Sr 45 # 5, Westonia Sr 24+ Sr 50 and Pavon Sr 24+ Sr 50 wheat lines were proved to be resistant to stem rust both under field and greenhouse conditions.

Wheat lines Sr 33/Cs # 4, Sr 45/Cs #24, Sr 45+Sr 2/Cs# 32, CS # 42, Westonia Sr 50+ Sr 26, Pavon Sr 24+ Sr 31+Sr 50, Sr45/Cs, Sr45+Sr2/Cs, Sr33/Cs, Sr33+Sr2/Cs, Sr24+31+50, Sr24+31, Lr34, Sr24+50, Sr26+31 and Lr67 were identified as resistant to leaf rust

Wheat lines Av Yr 15, WT6/12, Sr 33/Cs # 4, Sr 33/Cs #5, Sr 33+Sr 2/Cs #14, Sr 33+Sr 2/Cs #15, Sr 45/Cs #20 and Sr 45+Sr 2/Cs #29 were identified as resistant to yellow rust

Wheat lines with the genetic background of SrB, Sr32, Sr45, Sr50, Sr21, Lr67 and Lr34 were effective in resisting stem rust at field conditions and the combination of genes: Sr45+Sr2, Sr24+Sr50, Sr45+Sr50, Sr33+Sr45, Sr24+Sr31, Sr26+Sr31, Sr24+Sr31+Sr26, Sr24+Sr26, Sr50+Sr26 and also Sr24+Sr31+Sr50 were effective against stem rust at field conditions across all the three locations.Effectiveness of genes Yr15, YrSuj and Yr5+18 for resistance to yellow rust was confirmed. Resistant genes Lr34 and Lr67 were also proved effective against leaf rust.

Wheat lines Sr 50+Sr 45 # 35, Sr 45/Cs #20, Sr 45/Cs #21, Sr 45/Cs #25, Sr 45+Sr 2/Cs #29, Sr 45+Sr 2/Cs# 20, Sr 45+Sr 2/Cs# 33, Sr 45+Sr 2/Cs# 32, Thatcher+Lr 34, Westonia Sr 50+ Sr 26, Westonia Sr 24+ Sr 50 and Pavon Sr 24+ SR 26+Sr 31 across all test locations. Pavon Sr 24+ SR 26+Sr 31, was the only resistant gene both at field and greenhouse conditions.

The utilization of selected wheat lines needs the following precautions. (1) The wheat lines should be tested under diverse wheat producing field conditions representing various agro-ecologies; (2) The selected wheat lines with genes resistant to stem, yellow and leaf rusts needs to be confirmed and designated; (3) The frequency and distribution of races that are found to be virulent to resistance genes needs to be frequently and strictly monitored; and (4) In addition to disease resistance, parameters like yield potential and quality should be given due considerations in future breeding programs. Further criteria by farmers need to be considered to make breeding efforts more acceptable by the users.

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8. APPENDICES

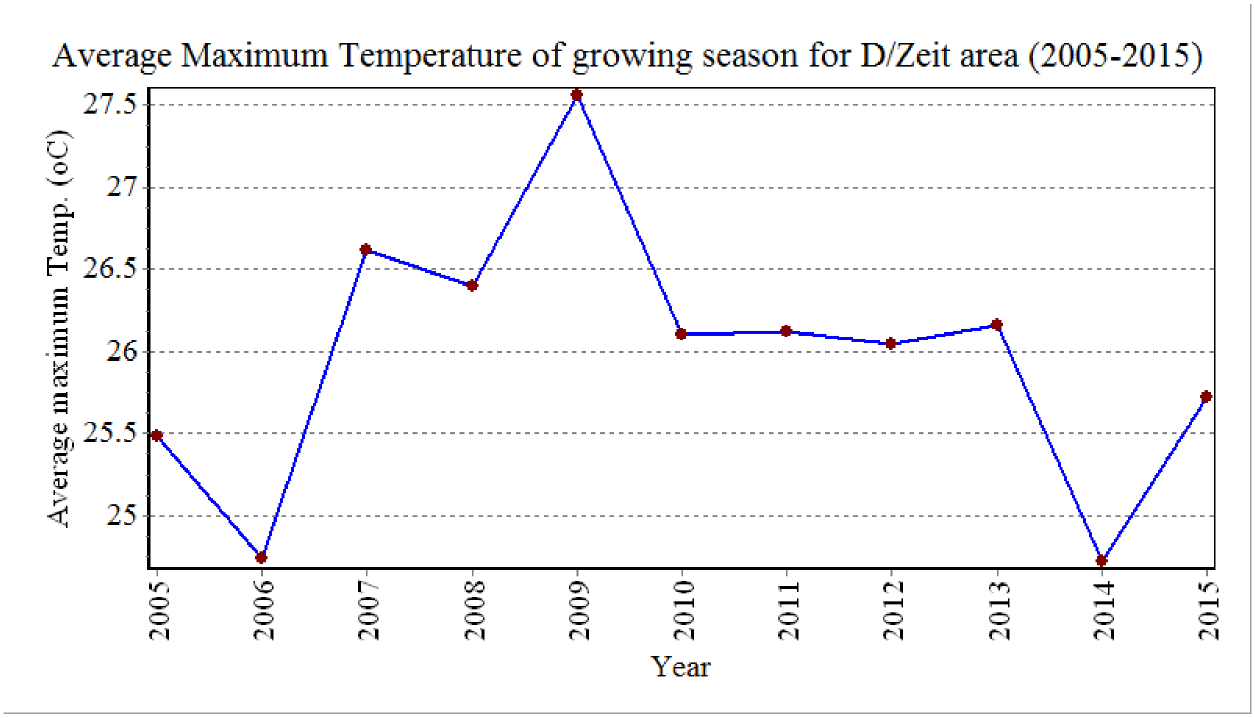

Figure.1 Average maximum temperature of growing season for Debrezeit area (2005-2015)

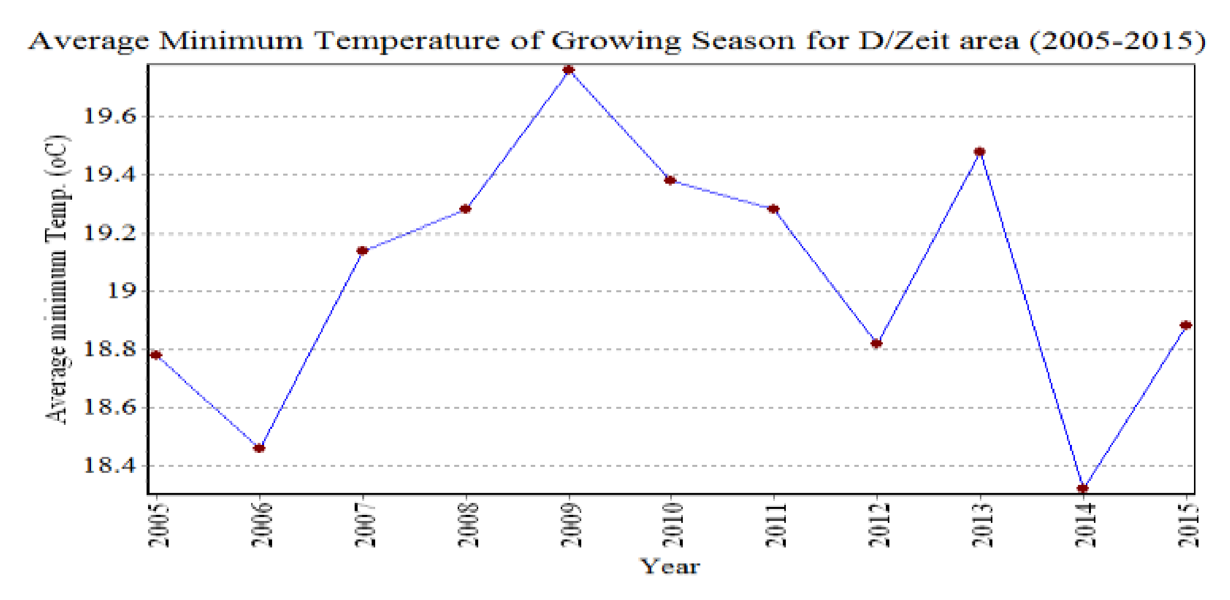

Figure 2 Average minimum temperatures of growing season for Debrezeit area (2005-2015).

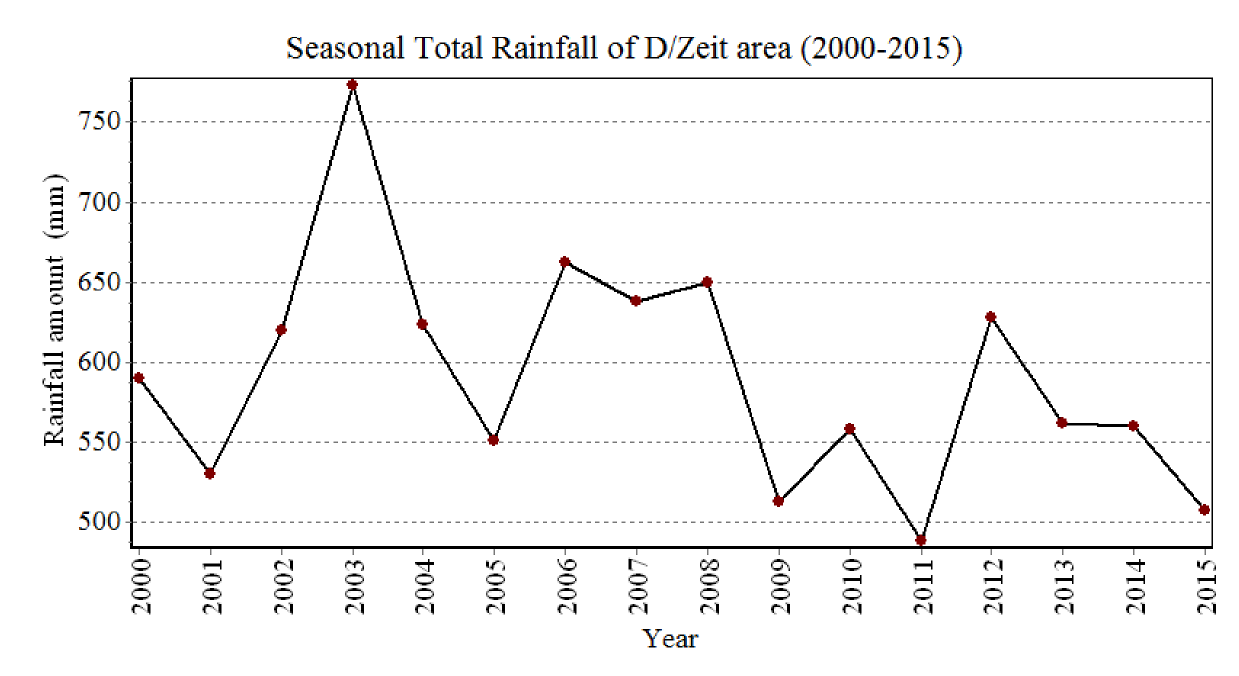

Figure 3 Seasonal total rainfall of Debrezeit area in mm (2000-2015)

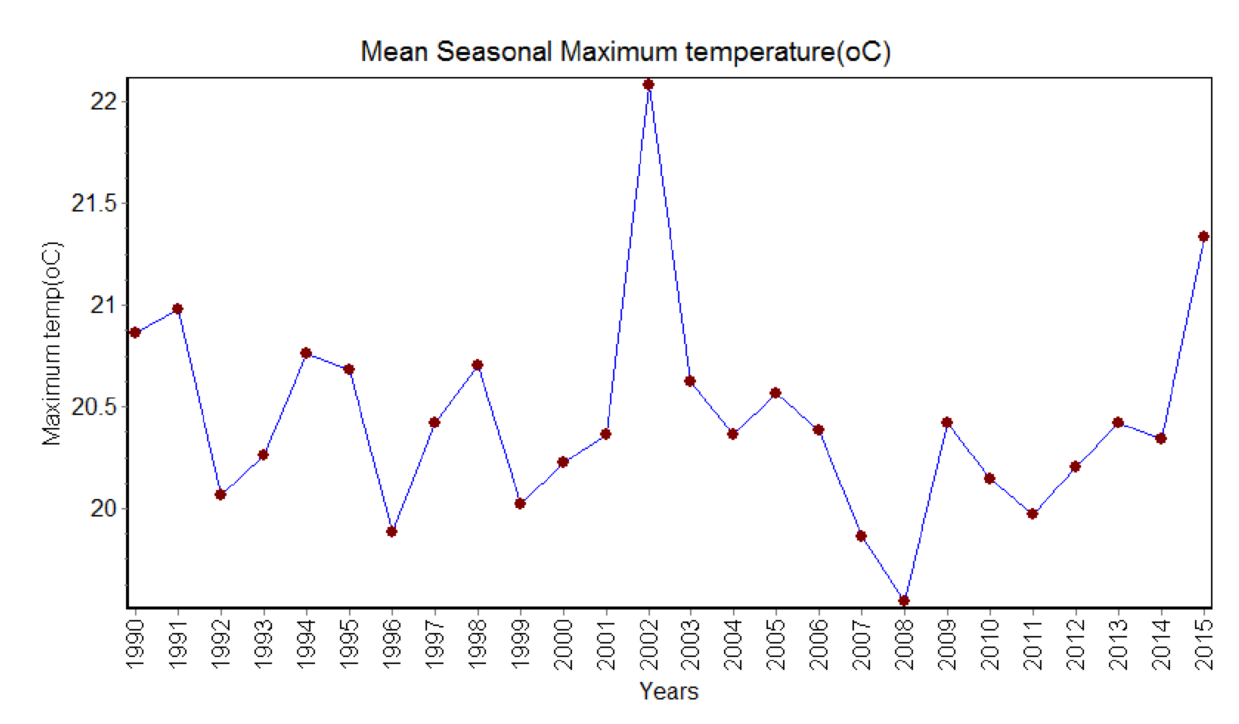

Figure 4 Mean Seasonal Maximum Temperature in ^{o}C of Sinana (1990-2015)

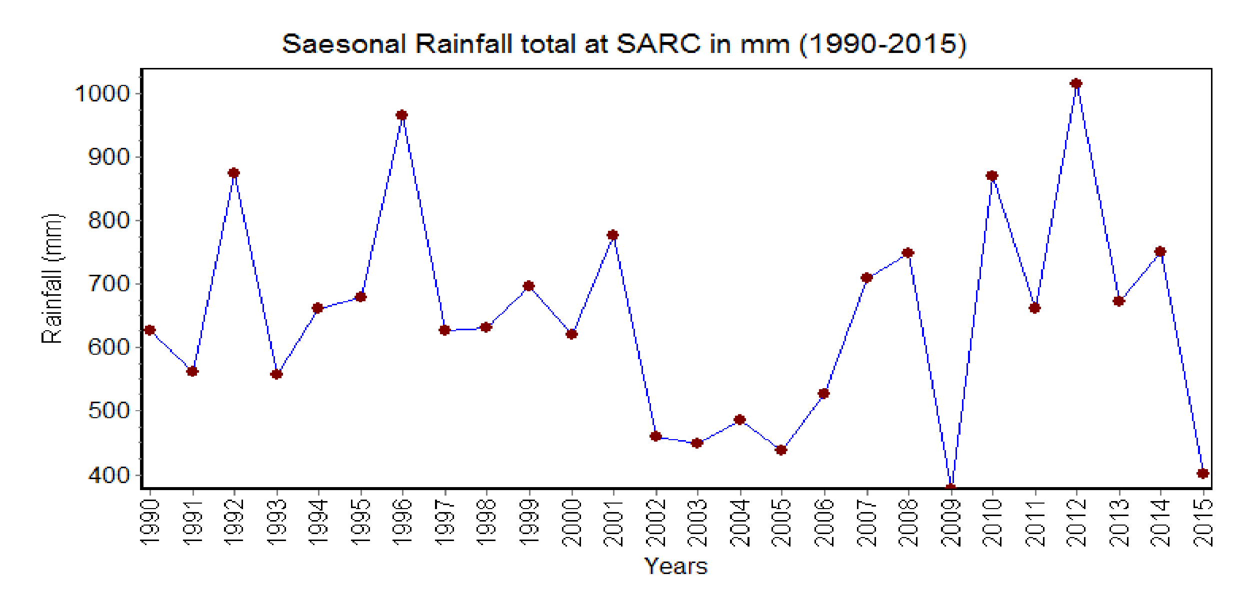

Figure.5 Seasonal rainfall total at Sinana in mm (1990-2015)

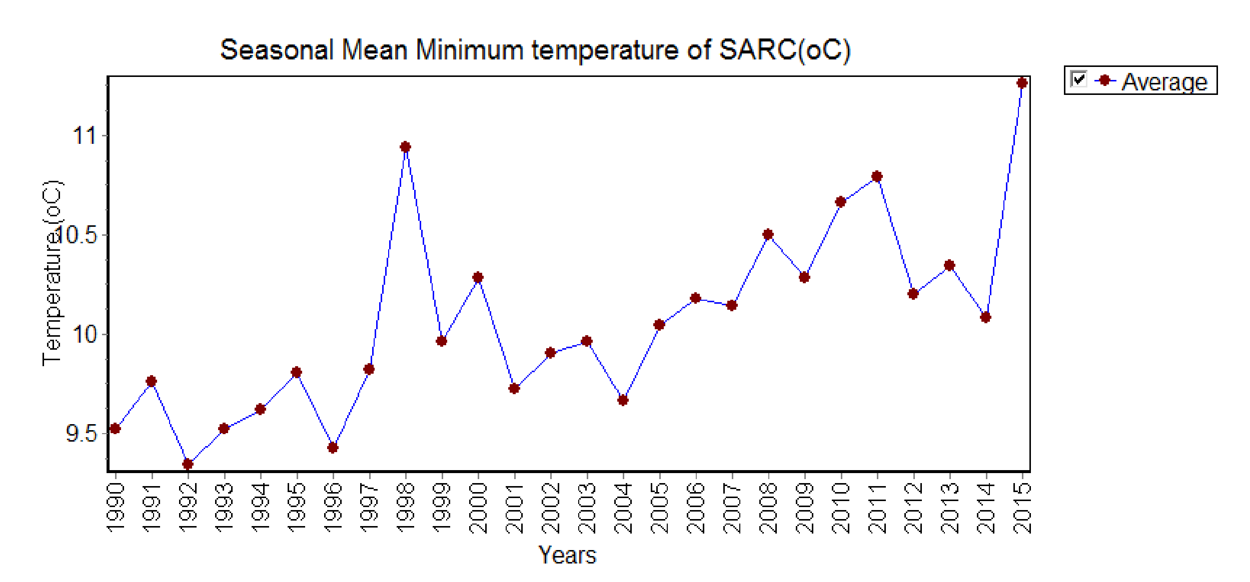

Figure .6 Seasonal Mean (Average) minimum temperature of Sinana area (1990-2015)

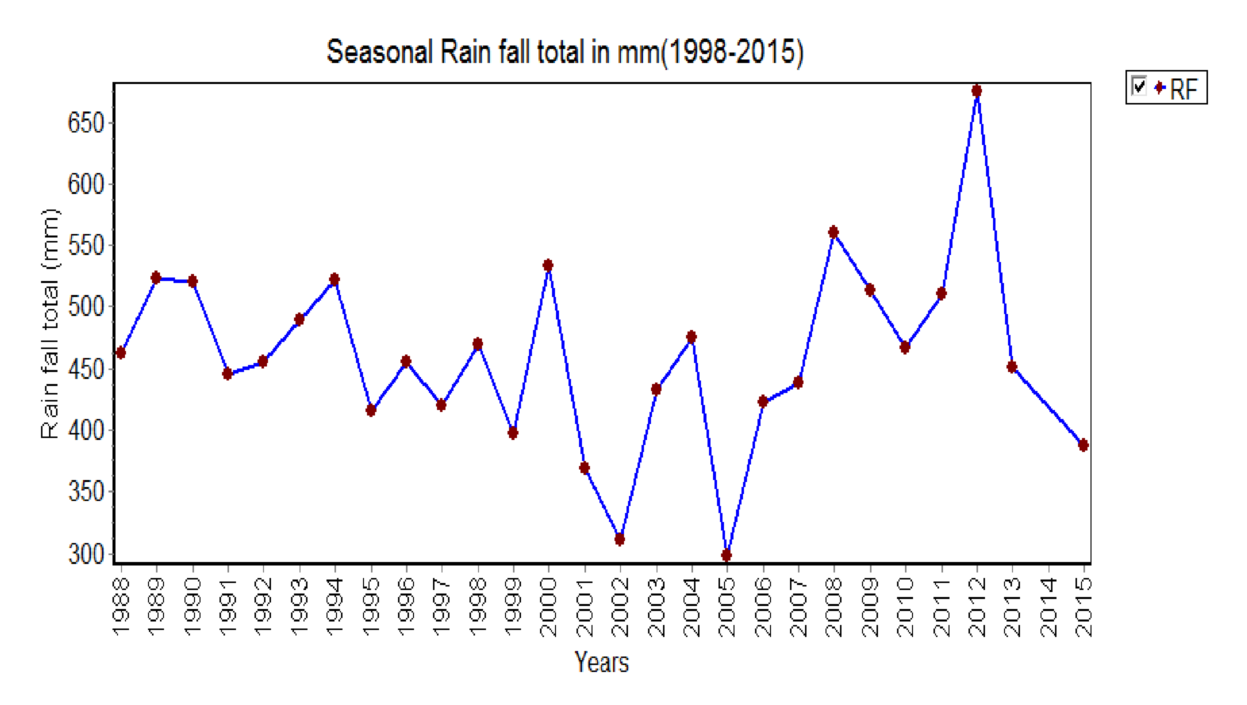

Figure 7 Seasonal total rainfall of Kulumsa in mm(1988-2015)

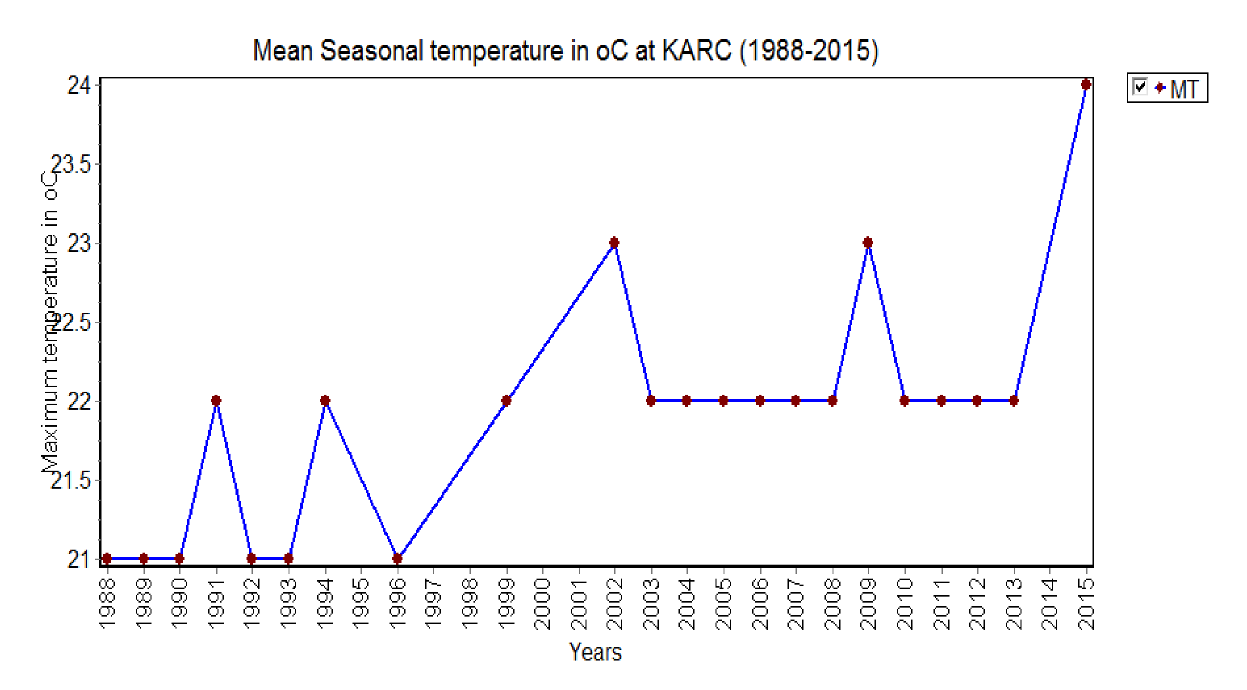

Figure 8 Seasonal Maximum temp of Kulumsa in ^{o}C

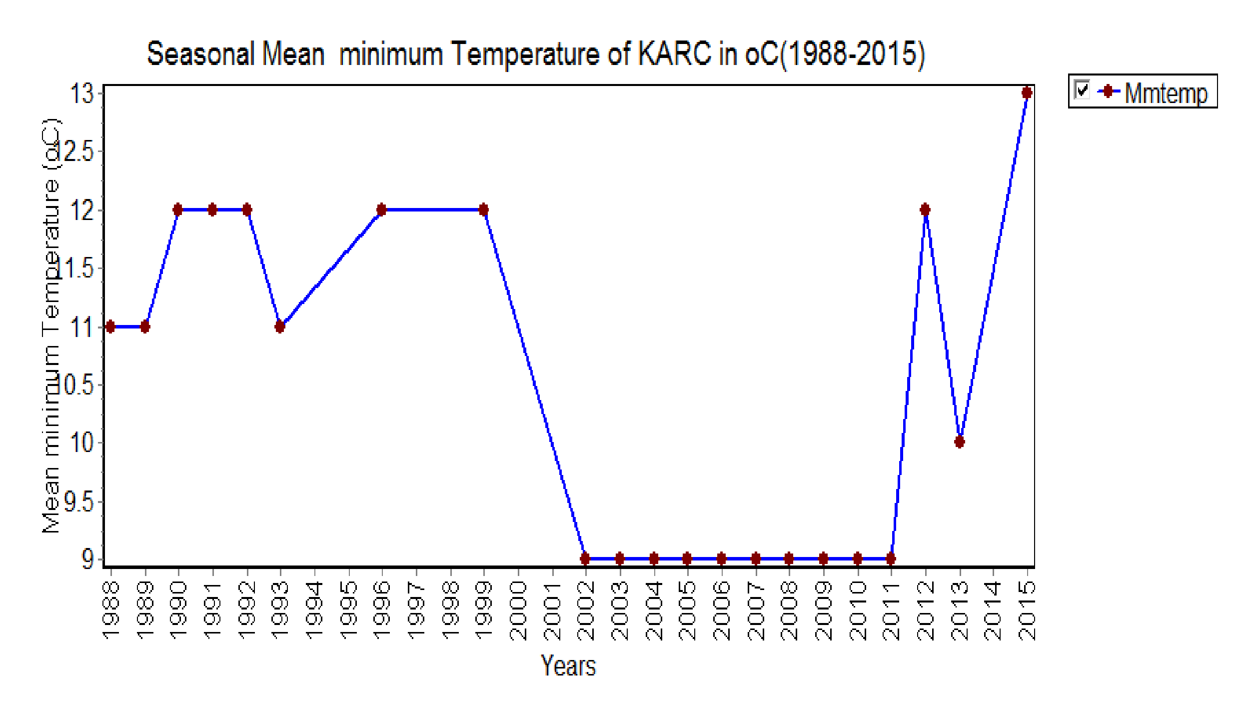

Figure 9 Seasonal Mean Minimum temperature of Kulumsa in ^{o}C (1988-2015)

Appendix Table 1. Wheat lines with known and unknown rust resistance genes and their pedigree

		Resistance genes		
S.N	Genotypes/ pedigree	Seedling resistance gene	APG	Source
1	Westonia	Control		
2	Wes+S46 (B4)	Sr46		Evans
3	Sujata	YrSuj	Yr46	Evans
4	C 591	YrSuj	Yr46	Evans
5	Av Yr 15	Yr15		Evans
6	Av 36-29-34#20	unnamed Yr	Different APR	Evans
7	Quaiv		Different APR	Evans
8	Av 36-29-18#5	Unnamed Yr	Different APR	Evans
9	WT6/12			Sam
10	Sr 33/WT 6/12	Sr33		Sam
11	LAG 672	Un named Sr and Yr gene		Evans
12	Wes+ S46(C5)	Sr46		Sam
13	Sr 33+Sr 45 #4	Sr33 Sr45		Sam
14	Sr 45/Kulin	Sr45		Sam
15	Kulin	unknown Sr gene		Sam
16	Sr 33+45 # 9	Sr33 Sr45		Sam
17	Sr 33+Sr 45 #23	Sr33 Sr46		Sam
18	Sr 33+Sr 45 #36	Sr33 Sr47		Sam
19	AvYr 5+18	Yr5	possibly with Yr18	Evans
20	Av 36-29-34# 10	unknown Yr gene		Evans
21	Av 36-29-34# 10	unknown Yr gene		Sam
22	Sr 50+Sr 45 # 1	Sr50 Sr 45		Sam
23	Sr 50+Sr 45 # 5	Sr50 Sr 46		Sam
24	Sr 50+Sr 45 # 7	Sr50 Sr 47		Sam
25	Sr 50+Sr 45 # 10	Sr50 Sr 48		Sam

Table 1. continued.

S.N	Genotypes/ pedigree	Resistance genes		source
		Seedling resistance gene	APG	
26	Sr 50+Sr 45 # 27	Sr50 Sr 49		Sam
27	Sr 50+Sr 45 # 28	Sr50 Sr 50		Sam
28	Sr 50+Sr 45 # 33	Sr50 Sr 51		Sam
29	Sr 50+Sr 45 # 35	Sr50 Sr 52		Sam
30	Sr 50+Sr 45 # 37	Sr50 Sr 53		Sam
31	Sr 33/Cs #1	Sr33		Sam
32	Sr 33/Cs # 2	Sr33		Sam
33	Sr 33/Cs # 4	Sr33		Sam
34	Sr 33/Cs #5	Sr33		Sam
35	Sr 33/Cs # 6	Sr33		Sam
36	Sr 33+Sr 2/Cs # 11	Sr33Sr2		Sam
37	Sr 33+Sr 2/Cs #12	Sr33Sr2		Sam
38	Sr 33+Sr 2/Cs #13	Sr33Sr2		Sam
39	Sr 33+Sr 2/Cs #14	Sr33Sr2		Sam
40	Sr 33+Sr 2/Cs #15	Sr33Sr2		Sam
41	Sr 45/Cs #21	Sr45		Sam
42	Sr 45/Cs #24	Sr45		Sam
43	Sr 45/Cs #25	Sr45		Sam
44	Sr 45/Cs #23	Sr45		Sam
45	Sr 45+Sr 2/Cs #28	Sr45 Sr2		Sam
46	Sr 45+Sr 2/Cs #29	Sr45 Sr2		Sam
47	Sr 45+Sr 2/Cs# 20	Sr45 Sr2		Sam
48	Sr 45+Sr 2/Cs# 33	Sr45 Sr2		Sam
49	Sr 45+Sr 2/Cs# 32	Sr45 Sr2		Sam
50	Sr 2/ Cs #19	Sr2		Sam

Table 1. continued.

S.N	Genotypes/ pedigree	Resistance genes Seedling resistance gene	APG	Source
51	Sr 2/ Cs # 51	Sr2		Sam
52	Sr 2/ Cs #48	Sr2		Sam
53	Sr 2/ Cs # 52	Sr2		Sam
54	Cs #39			Sam
55	Sr 2+Cs 49			Sam
56	Cs #28			Sam
57	Cs #40			Sam
58	Cs # 41			Sam
59	CS # 42			Sam
60	Sr 45+Cocamba	Sr45		Sam
61	Sr 21+Cocamba	Sr21		Sam
62	Sr 21/kulin	Sr21		Sam
63	Sr 22/CO 1213	Sr22		Sam
64	CO1213			Sam
65	Thatcher			Evans
66	Thatcher+Lr 34	Lr34		Evans
67	Cocamba			Evans
68	Thatcher+Lr 46	Lr46		Evans
69	Thatcher+Lr 67	Lr67		Evans
70	Avocet	Sr26		Evans
71	Avocet+Lr 67	Sr26 Lr67		Evans
72	CANTHACHK			Evans
73	CT4-NS1			Rohit
74	Westonia Sr 50+ Sr 26	Sr 50, sr26		Rohit
75	Pavon Sr 26+ SR 31	Sr26, Sr31		Rohit

Table 1. continued.

S.N	Genotypes/ pedigree	Resistance genes: Seedling resistance gene	APG	Source
76	Westonia Sr 24+ Sr 50	Sr24, sr50		Rohit
77	Pavon Sr 24+ Sr 50	Sr24, sr50		Rohit
78	Westonia Sr 24+ Sr 31	Sr24, Sr31		Rohit
79	Pavon Sr 24+ SR 26+Sr 31	sr24, Sr26, Sr31		Rohit
80	Westonia Sr 24+ Sr 26	Sr24, Sr26		Rohit
81	Pavon Sr 24+ Sr 31	Sr24, sr31		Rohit
82	Pavon Sr 24+ Sr 31+Sr 50	Sr24, Sr31, Sr50		Rohit
83	Sr Aes1t			Rohit
84	Gato Sr 50			Rohit
85	Co 1 NS 765			Rohit
86	Sr 39	Sr39		Rohit
87	Angas Sr 32	Sr32		Rohit
88	AEG 91586 WHEA(westonia+ Sr B			Rohit
89	CO1 NS 766			Rohit
90	SA 8123(Sr B)	SrB		Rohit
91	Columbus			Evans
92	ND Sr 1	repressed Sr gene		Evans
93	CTH- Ns 2			ICARDA
94	PFAU/MILAN//JAWAHIR-9			ICARDA
95	BOW/PRL//BUC/3/WH576/4/N-AZRAQ-2			ICARDA
96	TEVEE'S'/BOBWHITE #1//ASEEL-1			ICARDA
97	TEVEE'S'/BOBWHITE #1//ASEEL-1			ICARDA
98	WATAN-6//SKAUZ/2*STAR			ICARDA
99	Sids-12			ICARDA
100	WATAN-6//SKAUZ/2*STAR			ICARDA

Table 1. Continued

S.N	Genotypes/ pedigree	Resistance genes: Seedling resistance gene	Resistance genes: APG	Source
101	WATAN-6//SKAUZ/2*STAR			ICARDA
102	WATAN-6//SKAUZ/2*STAR			ICARDA
103	WATAN-6//SKAUZ/2*STAR			ICARDA
104	DEBEIRA//SHUHA-8/DUCULA			ICARDA
105	DEBEIRA//SHUHA-8/DUCULA			ICARDA
106	DEBEIRA//SHUHA-8/DUCULA			ICARDA
107	DEBEIRA//SHUHA-8/DUCULA			ICARDA
108	SERI.1B//KAUZ/HEVO/3/AMAD/4/ESWYT99#18/ARRIHANE			ICARDA
109	SERI.1B//KAUZ/HEVO/3/AMAD/4/ESWYT99#18/ARRIHANE			ICARDA
110	OPATA/RAYON//KAUZ/3/MILAN/DUCULA			ICARDA
111	Attila-7 (Check)			ICARDA
112	PFAU/MILAN//MOONTASIR-3			ICARDA
113	PFAU/MILAN//MOONTASIR-3			ICARDA
114	PFAU/MILAN//MOONTASIR-3			ICARDA
115	DAJAJ-5/4/CHEN/AEGILOPS SQUARROSA (TAUS)//BCN/3/KAUZ			ICARDA
116	DAJAJ-5/4/CHEN/AEGILOPS SQUARROSA (TAUS)//BCN/3/KAUZ			ICARDA
117	DAJAJ-5/4/CHEN/AEGILOPS SQUARROSA (TAUS)//BCN/3/KAUZ			ICARDA
118	DAJAJ-5/4/CHEN/AEGILOPS SQUARROSA (TAUS)//BCN/3/KAUZ			ICARDA
119	DAJAJ-5/4/CHEN/AEGILOPS SQUARROSA (TAUS)//BCN/3/KAUZ			ICARDA
120	DAJAJ-5/4/CHEN/AEGILOPS SQUARROSA (TAUS)//BCN/3/KAUZ			ICARDA
121	HADIAH-14/QAMAR-1			ICARDA
122	HUBARA-13/MOONTASIR-3			ICARDA
123	HUBARA-13/MOONTASIR-3			ICARDA
124	HUBARA-1/5/KAUZ/3/MYNA/VUL//BUC/FLK/4/MILAN			ICARDA
125	HUBARA-1/5/KAUZ/3/MYNA/VUL//BUC/FLK/4/MILAN			ICARDA

Table 1.Continued

S.N	Genotypes/ pedigree	Resistance genes Seedling resistance gene	 APG	Source
126	HUBARA-1/5/KAUZ/3/MYNA/VUL//BUC/FLK/4/MILAN			ICARDA
127	HUBARA-1/5/KAUZ/3/MYNA/VUL//BUC/FLK/4/MILAN			ICARDA
128	HUBARA-1/5/KAUZ/3/MYNA/VUL//BUC/FLK/4/MILAN			ICARDA
129	TEVEE-1/SD 8036//MOONTASIR-2			ICARDA
130	SOSSI-7//MILAN/PASTOR			ICARDA
131	SOSSI-7//MILAN/PASTOR			ICARDA
132	JAWAHIR-6/QAMAR-5			ICARDA
133	JAWAHIR-6/QAMAR-5			ICARDA
134	JAWAHIR-8/ZEMAMRA-8			ICARDA
135	ZAIEM-4/5/JUN//MAYA/MON/3/PGO/4/MILAN			ICARDA
136	ZAIEM-4/5/JUN//MAYA/MON/3/PGO/4/MILAN			ICARDA
137	SERI.1B//KAUZ/HEVO/3/AMAD/4/MILAN/PASTOR			ICARDA
138	SERI.1B//KAUZ/HEVO/3/AMAD/4/MILAN/PASTOR			ICARDA
139	HUITES/4/CS/TH.SC//3*PVN/3/MIRLO/BUC/5/MOONTSIR-3			ICARDA
140	DEBEIRA			ICARDA
141	DEBEIRA			ICARDA
142	ALMAZ-8/FLAG-4			ICARDA
143	ALMAZ-8/FLAG-4			ICARDA
144	KBG-1 (Check)			ICARDA
145	ALMAZ-15/SOMAMA-3			ICARDA
146	ALMAZ-15/SOMAMA-3			ICARDA
147	ALMAZ-19/ZEMAMRA-8			ICARDA
148	Sids-12			ICARDA
149	BACANORA T 88/RUTH-2			ICARDA
150	BACANORA T 88/RUTH-2			ICARDA

Table 1. Continued

S.N	Genotypes/ pedigree	Resistance genes: Seedling resistance gene	Resistance genes: APG	Source
151	BACANORA T 88/RUTH-2			ICARDA
152	CHAM-8/RUTH-3			ICARDA
153	TEVEE'S'/BOBWHITE #1//ASEEL-1			ICARDA
154	TEVEE'S'/BOBWHITE #1//ASEEL-1			ICARDA
155	ALMAZ-11/3/PASTOR/FLORKWA-1//PASTOR			ICARDA
156	ALMAZ-8/FLAG-4			ICARDA
157	CHAM-6/SHUHA-14//ETBW 4921			ICARDA
158	CHAM-6/SHUHA-14//ETBW 4921			ICARDA
159	DEZ/ETBW 4919			ICARDA
160	DEZ/ETBW 4919			ICARDA
161	LFN/II58.57//PRL/3/HAHN/4/KAUZ/5/KAUZ/6/ETBW 4920			ICARDA
162	LFN/II58.57//PRL/3/HAHN/4/KAUZ/5/KAUZ/6/ETBW 4920			ICARDA
163	LFN/II58.57//PRL/3/HAHN/4/KAUZ/5/KAUZ/6/ETBW 4920			ICARDA
164	LFN/II58.57//PRL/3/HAHN/4/KAUZ/5/KAUZ/6/ETBW 4920			ICARDA
165	LFN/II58.57//PRL/3/HAHN/4/KAUZ/5/KAUZ/6/ETBW 4920			ICARDA
166	VEE#5/SARA//DUCULA/3/NJORO SD-7			ICARDA
167	PFAU/MILAN//ETBW 4921			ICARDA
168	RABIH-10/ETBW 4922			ICARDA
169	BAOBAB-1//MILAN/PASTOR			ICARDA
170	BAOBAB-1//MILAN/PASTOR			ICARDA
171	GOUMRIA'S'/NJORO SD-7			ICARDA
172	GOUMRIA-3/ETBW 4920			ICARDA
173	HUBARA-5/ETBW 4922			ICARDA
174	HUBARA-5/EALME4SA -167			ICARDA
175	HUBARA-1/ETBW 4921			ICARDA

Table 1. Continued

S.N	Genotypes/ pedigree	Resistance genes: Seedling resistance gene	APG	Source
176	HUBARA-1/ETBW 4921			ICARDA
177	HUBARA-1/ETBW 4921			ICARDA
178	MILAN/PASTOR//FLAG-5			ICARDA
179	SOMAMA-9/ETBW 4921			ICARDA
180	OPATA/RAYON//KAUZ/3/ACHTAR/INRA 1764			ICARDA
181	BOW/PRL//BUC/3/WH576/4/ETBW 4919			ICARDA
182	PASTOR/3/VEE#5//DOVE/BUC/4/ETBW 4919			ICARDA
183	PASTOR/3/VEE#5//DOVE/BUC/4/ETBW 4919			ICARDA
184	SERI*3//RL6010/4*YR/3/PASTOR/4/BAV92/5/ETBW 4921			ICARDA
185	SERI*3//RL6010/4*YR/3/PASTOR/4/BAV92/5/ETBW 4921			ICARDA
186	HAMAM-4/FAISAL-1			ICARDA
187	HAMAM-4/FAISAL-1			ICARDA
188	KBG-01//MILAN/PASTOR			KARC
189	Shorima/ UTQUE96/3/PYN/BAU//MILAN			KARC
190	Honqolo/ NJORO SD-7			KARC
191	Danda'a/ KIRITATI//2*PBW65/2*SERI.1B			KARC
192	Kingbird/ TAM200/TUI/6/PVN//CAR422/ANA/5/BOW/CROW//BUC/PVN/3/YR/4/TRAP#1			KARC
193	Kakaba/ KIRITATI//SERI/RAYON			KARC
194	Hidasse/ YANAC/3/PRL/SARA//TSI/VEE#5/4/CROC-1/AE.SQUAROSA(224)//OPATTA			
195	Millenium/ALD/CEP75630//CEP75234/PT7219/3/BUC/BIY/4/			KARC
196	Digalu/ SHA7/KAUZ			KARC
197	Pavon 76/ VCM//CNO"S"/7C/3/KAL/BB			KARC
198	Ogolcho/ WORRAKATTA/2*PASTOR			KARC
199	Madda Walabu/ TI/3/FN/TH/NAR 59 *2/4/BOL'S'			SARC
200	Sofumer/ LIRA 'S'/TAN"S"			SARC
201	Dambal/ AGUILAL/3/PYN/BAU//MILAN			SARC
202	Obora/ UTIQUE96/FLAG-1			SARC
203	Mandoyu/ WORRAKATTA/PASTOR			SARC
204	Sanate/ 14F/HAR 1685			SARC

9. BIOGRAPHY

The author was born in Amola tebo, Arsi sire on September 17, 1987. He joined Tebo chacha Primary school in 1996 until he completed his grade 6 lesson and then he join Haile abba mersa primary and Junior School to study his grade 7 and grade 8. After taking the national examination for grade eight, he joined sire high school and continuing his progress to grade 9 and 10 at sire senior secondary preparatory school and then after taking grade 10 national examination in 2004 and he joined into grade 11 until he finishes his study and takes his grade 12 entrance exam in 2007 at the same school and he join Haramaya university collages of agriculture in 2007 and studied in crop production and protection department and graduated with B.Sc degree in 2010. Then he was employed under Oromia Agricultural Research Institute which is based at Mechara as junior researcher from November 2010 - November 2011. Then he was employed by Ethiopian Ministry of Agriculture as junior instructor based at Agarfa College and then he re-employed on august 2012 by Ethiopian Agricultural Research Institute based at Kulumsa Agricultural Research Center and he joined protection department worked on protection section until he left for second degree in Hawassa University. Currently, he is prospective graduate student of Hawassa University specializing in plant protection leading to M.Sc. degree.