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Research Paper

Leveraging on germplasm acquisition for Arabica coffee improvement in Kenya

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Abstract. The low genetic variability within *Coffea arabica* species is a major hindrance to its improvement. The emergence of new pathogen races, especially for the prevalent fungus *Hemileia vastatrix* causing Coffee Leaf Rust (CLR) is a challenge to coffee production worldwide. Two accessions, namely Selection 5A and Selection 6 were received in 2008 from India as part of germplasm exchange in a Coffee Leaf Rust collaborative project involving India and four African countries namely, Uganda, Zimbabwe, Rwanda and Kenya. Seedlings of two Kenyan commercial varieties SL 28 and Ruiru 11 representing susceptible and resistant varieties respectively were also raised alongside the Indian accessions. The seedlings of the four varieties were planted at Coffee Research Institute (CRI) sub-centre in Kisii country and Agricultural Training Centre in Machakos country for field evaluation. Data was recorded on growth and yield parameters before and after crop bearing. Field records were also taken for infection by Coffee Berry Disease (CBD) and Coffee Leaf Rust (CLR). Growth parameters related to crop bearing had stronger correlation with actual berry count and hence yield confirming that potential yield of a coffee variety can accurately be predicted by combining early measurements of growth parameters and yield records. The yield potential of the Indian accessions was found to be lower than the standard Kenyan varieties. However, the accessions were outstanding in resistance to CLR which was only comparable to the resistant Ruiru 11 variety. The study confirmed that CLR, if not controlled can erode the high yield potential of elite varieties if conditions are favorable. It was also concluded that the Indian accessions provides an opportunity upon which traditional Kenyan commercial cultivars can be improved to withstand existing and new races of the rust pathogen.

Keywords: Coffee Leaf Rust, Coffee Berry Disease, yield, India, Kenya.

INTRODUCTION

Arabica coffee constitutes about two thirds of the world's coffee production while Robusta coffee constitutes the rest (Gichuru et al., 2008; Gichimu and Omondi, 2010a, Cheserek et al, 2015). Despite its predominance, Arabica coffee has a narrow genetic base that poses a challenge to its improvement. *Coffea arabica* originated in the Kaffa region in the South West highlands of Ethiopia from where it was dispersed by traders to other regions of the world. It has two distinct botanical varieties; *Coffea arabica* var. *arabica* (usually called Typica) and *C. arabica* var *bourbon* (usually called Bourbon) (Hue, 2005; Gichimu and Omondi, 2010b). The Typica genetic base originated from a single plant in Indonesia which was subsequently cultivated in the Amsterdam Botanical Garden in the early 18th Century (around 1715) while the Bourbon genetic base originated from a few coffee trees introduced from Mocha (Yemen) to the Bourbon Island (now La Reunion) at about the same time (Hue, 2005; Gichimu and Omondi, 2010b). The low genetic variability of *C. arabica* is attributed to its narrow geographic origin,

an allotetraploid genome formed through hybridization of diploid *C. canephora* and *C. eugeinoides*, autogamous nature of reproduction and recent speciation (Lashermes et al., 1999). In contrast, Robusta coffee is largely outcrossing and genetically diverse. Genetic variability is one of the fundamental requirements in crop improvement.

In Kenya, coffee was introduced in the early 20th Century by missionaries that gave rise to a special variety of coffee that was christened "French Mission" coffee. From this pool the Kenyan commercial varieties, SL 28, SL 34 and K7 were selected. Concerns over the loss of genetic diversity triggered a series of collection missions by the Food and Agricultural Organization (FAO) of the United Nations, the Organization de Recherche Scientifique et Technique OutreMers (ORSTOM), (now the Institut de Recherche pour le Developpement [IRD]), the Centre de Cooperation International en Recherche Agronomic pour le Developpement (CIRAD), and International Board of Plant Genetic Resources (now Biodiversity International) (Meyer et al., 1968; Dulloo et al., 2009). Interspecific hybrids between *C. arabica* and *Coffea canephora* and subsequent genetic recombination through selfing and backcrossing have also been used to create variability upon which improved varieties can be developed (Omondi and Owuor, 1992; Gimase et al., 2014, 2015).

The Coffee Berry Disease (CBD) epidemics experienced in the late 1960's affected all the Kenyan commercial varieties and threatened to wipe out the coffee industry. The varieties were also susceptible to Coffee Leaf Rust (CLR). In the subsequent years, focus shifted to management of CBD and CLR using chemical and cultural practices (Hindorf and Omondi, 2011). Despite intensive fungicide sprays, disease epidemics, especially CBD, still contributed to significant economic losses, especially during prolonged cool and wet weather conditions. Analysis of coffee production costs further revealed that chemical control of CBD alone contributed up to 30% of the total production costs (Nyoro and Sprey, 1986). Most small holder farmers who could not afford the cost of spraying ended up applying one or two rounds which was found to aggravate the disease to higher proportions than what was observed on non-sprayed plots. The chemicals were also found to contaminate the environment and continuous application of the systemic types triggered the emergence of fungicide resistance in the pathogen population (King'ori and Masaba, 1991; Mwang'ombe et al., 1992).

Arising from these challenges, a major acquisition of coffee germplasm from other coffee growing countries was initiated. A large collection of Ethiopian accessions was received from the FAO and ORSTOM missions (Omondi, 1994). Other accessions came from Central and South America, Asia and exploration missions in natural coffee habitats in Africa. These coffee accessions contributed significantly to the pool of coffee genotypes upon which sources of genes conferring resistance to CBD and CLR were identified. Of special importance was the genotype Rume Sudan which originated from Boma Plateau in the Sudan. It was found to carry CBD resistance genes on two loci designated as R- and k- (Van der Vossen and Walyaro, 1980). The R-gene is dominant while the k-gene is recessive. Two alleles of the R-gene were identified with R_1R_1 in Rume Sudan and R_2R_2in Pretoria. Another dominant gene designated T-gene was found in Clone 1349/269 of Hibrido de Timor which was a natural interspecific hybrid found in the Timor Island (Omondi et al., 2001). Other hybrid derivatives from Hibrido de Timor such as Catimor also carry the T-gene. Catimor also confers resistance to most races of CLR in addition to being compact in growth. Most of these varieties have been used in the Kenyan breeding programme to develop Ruiru11 and Batian coffee cultivars that combine resistance to CBD and CLR with high yield and superior bean and cup quality.

In recent years, it has become apparent that the limited number of resistance genes so far identified cannot provide a sustainable long term resistance to the two diseases. Of the three genes that confer resistance to CBD, the recessive k-gene cannot be expressed in the hybrid Ruiru 11 because the Catimor mother parent lacks the gene. Therefore, only one or two genes operate in the Ruiru 11 population. The pureline Batian variety may carry up to three genes but certain lines within the population may be carrying one or two genes. This potential narrow genetic base is prone to breakdown in case there are genetic changes in the pathogen population. Previously only six races of CLR pathogen were known to exist in Kenya (Thitai and Okioga, 1977). However, six more new races have been detected recently (Gichuru et al., 2012; Ligabo et al., 2015).

Priority should therefore focus on identification of new sources of resistance to CBD and CLR and their incorporation into the improved varieties to widen the genetic base. This paper discusses field evaluation results of two Indian accessions known for their resistance to several races of CLR alongside Kenyan varieties, SL 28 (susceptible) and Ruiru 11 (resistant).

MATERIALS AND METHODS

Two accessions, namely Selection 5A and Selection 6 were received from India in 2008 as part of germplasm exchange in a Coffee Leaf Rust collaborative project involving India and four African countries of Uganda, Zimbabwe, Rwanda and Kenya. The seeds were raised in the nursery at the Coffee Research Institute of the Kenya Agricultural and Livestock Research Organization (KALRO-CRI). Seedlings of two Kenyan commercial varieties SL 28 and Ruiru 11 representing susceptible and resistant varieties respectively were also raised alongside the Indian accessions. After 12 months in the nursery, the seedlings were transferred to CRI sub-centre in Kisii and Agricultural Training Centre in Machakos for

field establishment.

Description of trial sites

Coffee Research Institute-Kisii (CRI-Kisii) subcentre is situated on latitude 0° 41' 0 S and longitude 34° 46' 0 E. It has deep clay soils with elevation of 1,700 m above sea level and generally receives rainfall throughout the year. Machakos ATC is situated on latitude 1° 31' S and longitude 37° 16' E. It has a semi-arid climate with an elevation of 1,137 m above sea level and the soils are sandy.

Experimental design, data collection and analysis

The trial was laid in a three replicate Randomized Complete Block Design. Each treatment comprised of a row of 10 seedlings of each of the 4 varieties planted at a spacing of 2 m × 2 m. Two guard rows of SL 28 variety was planted around the field trial. Supply of nutrients and management of weeds were done in accordance with Coffee Production Recommendations Handbook (Coffee Research Foundation, 2006). In the initial years of growth, records were taken after 12 months on the following parameters divided into two subsets comprising of (1); growth characters taken before observing the initial crop bearing parameters: girth (cm), height (cm), number of nodes, internode length on main stem (cm), number of primary branches, longest primary branches (cm), number of nodes on longest primary branches, internode length on primary branches (cm) and number of laterals and (2); initial bearing parameters especially related to berry count including: bearing primary branches, number of nodes on bearing primary branches, bearing nodes, number of berries, berries per node and nodes with highest berries.

Subsequently, each tree was scored for CLR and CBD infection on monthly basis and a monthly mean computed for each treatment. CLR was scored on a scale of 0 to 10 where, 0 = No infection, 1 = 1 to 10% infection, 2 = 11 to 20% infection, 3 = 21 to 30% infection, 4 = 31 to 40% infection, 5 = 41 to 50% infection, 6 = 51 to 60% infection, 7 = 61 to 70% infection, 8 = 71 to 80% infection, 9 = 81 to 90% infection and 10 = 91 to 100% infection. CBD was scored by counting infected berries on three marked branches and expressed as a percentage of total berries on the three branches. The scoring for both CLR and CBD were done monthly until the disease progress started to decline. The month with the peak score was used for data analysis. Yield data was also recorded by cumulatively harvesting and weighing ripe cherries in grams per tree over the cropping season. Disease and yield data were recorded for three years.

Growth data was subjected to correlation analysis to determine the best parameters that could be used for yield prediction in the early stages of plant growth. Disease and yield data were subjected to analysis of variance (ANOVA) to determine significant differences among treatments and their means were separated by Duncan's Multiple Range Test.

RESULTS

Correlation results among growth and yield related parameters are presented in Table 1. Apart from girth which had a significant positive correlation ($p \leq 0.05$) with % bearing nodes and berries per node, both of which are related to yield, all other growth characters had weak correlation with initial bearing parameters. As expected, correlation tended to be significant between characters within a subset. Another significant observation was that internode length on main stem had negative correlation with all characters except with internode length on primary branches. It is notable that number of berries and berries per node which are the best indicators of yield, had positive and significant correlation with bearing primary branches and % bearing primary branches.

Yield at CRI-Kisii was significantly ($P \leq 0.01$) influenced by the main effects of genotype and year (Table 2). The interaction between genotypes x year was also significant ($P \leq 0.05$). CBD score at CRI-Kisii was not significantly influenced by the main effects or their interactions. In contrast, the influence of the main effects and their interaction on CLR was highly significant ($P \leq 0.01$).

The mean cherry yield in grams/tree at CRI-Kisii are presented in Figure 1. Ruiru 11 recorded the highest yields in years 1 (2010/2011) and 2 (2011/2012) followed by Selection 6, SL 28 and Selection 5A in that order. Yields in year 3 (2012/2013) were depressed for all varieties but SL 28 recorded the highest yields during that period and was followed in decreasing order by Ruiru 11, Selection 6 and Selection 5A. Minimal CBD infection was observed on the susceptible SL 28 cultivar in years 2 and 3 (Figure 2). CLR infection on SL 28 was low in Years 1 and 2 (less than 10% infection) but increased significantly in year 3 which recorded infection of almost 40%. (Figure 3).

At Machakos ATC, yield was significantly affected by main effects of genotypes and year (Table 3). The genotype x year interaction effect was also significant. There was no CBD infection at Machakos ATC on all varieties. However, effect of genotype and genotype x year interaction were significant for CLR infection. Figure 4 indicates that yields in year 1 were highest in SL 28, intermediate in Ruiru 11 and Selection 6 but lowest in Selection 5A. Yields in year 2 were depressed but Selection 5A recorded the least cherry weight compared to the other 3 varieties which recorded similar yields. SL 28 and Ruiru 11 recorded high yields in year 3 but yields for the Indian accessions remained low during the same period. CLR was observed on the susceptible SL 28 and

Table 1. Correlation among growth and yield parameters measured on four Arabica coffee varieties.

Variables	G	H	#N	ILMS	#PB	BPB	%BPB	LPB	#NLPB	ILPB	#NBPB	%BN	#L	#B	B/N
H	0.284														
#N	0.434*	0.630***													
ILMS	-0.273	0.379	-0.465*												
#PB	0.643***	0.325	0.728***	-0.542**											
BPB	0.294	0.257	0.262	-0.037	0.277										
%BPB	0.306	0.239	0.236	-0.037	0.288	0.995***									
LPB	0.740***	0.431*	0.475*	-0.138	0.596**	0.326	0.319								
#NLPB	0.682***	0.194	0.536**	-0.512*	0.773***	0.367	0.371	0.785***							
ILPB	0.307	0.416*	0.062	0.419*	-0.062	0.035	0.018	0.600**	-0.022						
#NBPB	0.135	0.192	0.219	-0.018	0.024	0.576**	0.528**	0.286	0.252	0.111					
%BN	0.412*	0.383	0.312	0.044	0.309	0.837***	0.828***	0.445*	0.391	0.178	0.690***				
#L	0.537**	0.209	0.166	-0.057	0.496*	0.392	0.407*	0.667***	0.780***	0.051	0.317	0.432*			
#B	0.167	0.189	0.220	-0.023	0.020	0.542**	0.493*	0.278	0.233	0.127	0.956***	0.674***	0.276		
B/N	0.444*	0.142	0.146	-0.058	0.258	0.732***	0.734***	0.453*	0.470*	0.105	0.640***	0.910***	0.518**	0.644***	
NHB	0.203	0.152	0.136	0.011	-0.021	0.497*	0.454*	0.289	0.232	0.149	0.937***	0.625**	0.305	0.968***	0.655***

Key: G = Girth (cm), H = Height (cm), #N = Number of Nodes, ILMS = Internode Length on main stem (cm), #PB = Number of primary branches, BPB = Bearing primary branches, %BPB = % Bearing primary branches, LPB = Longest primary branches (cm), #NLPB = Number of nodes on longest primary branches, ILPB = Internode length on primary branches (cm), #NBPB = Number of nodes on bearing primary branches, %BN = % Bearing nodes, #L = Number of laterals, #B = Number of berries, B/N = Berries per node and NHB = Nodes with highest berries,* = Significant at P≤0.05, ** = Significant at P≤0.01, *** = Significant at P≤0.001.

highest infection was recorded in year 2. Infection in years 1 and 3 were low.

DISCUSSION

Early determination of coffee yield is hampered by the long juvenile period of the coffee plant and the need to take repeated measurements over a complete cropping cycle of up to five years. Indirect selection for yield using growth components combined with one or two years of yield data has been considered as a possible means of shortening the time required to determine the yield potential of a coffee variety. There are two categories of growth and early yield parameters; (1) those that can be recorded before crop bearing namely, girth (cm), height (cm), number of nodes, internode length on main stem (cm), number of primary branches, longest primary branches (cm), number of nodes on longest primary branches, internode length on primary branches (cm) and number of laterals and (2) those that are related to initial crop bearing which can be recorded within two years after planting including bearing primary branches, number of nodes on bearing primary branches, bearing nodes, number of berries, berries per node and nodes with highest berries.

Correlation between parameters in these two subsets can be used to predict the yield potential of a variety. In the first subset of growth parameters taken before crop bearing, it was only stem girth that had positive significant correlation with a crop bearing parameter (berries per node). Parameters related to crop bearing had stronger correlation with actual berry count and hence yield. This confirms the findings by Walyaro and Van der Vossen (1979)

Table 2. Analysis of variance results for yield, CBD and CLR scores at Kisii.

Source	DF	Yield		CBD		CLR	
		Mean Square	Probability	Mean Square	Probability	Mean Square	Probability
Reps	2	1277799.80	0.04*	0.0495211	0.39^{NS}	0.0330864	0.120^{NS}
Main effects							
Genotype	3	6095623.10	0.00***	0.0612037	0.33^{NS}	7.4104944	0.000***
Year	2	3547756.30	0.00***	0.9022802	0.42^{NS}	2.5801235	0.000***
Interactions							
Genotype × Year	6	873134.40	0.04*	0.0458261	0.51^{NS}	2.5801235	0.000***
Error	22	331622.60		0.0507892		0.0247363	

Key:
NS = Not Significant
* = Significant at P ≤ 0.05
** = Significant at P ≤ 0.01
*** = Significant at P ≤ 0.001

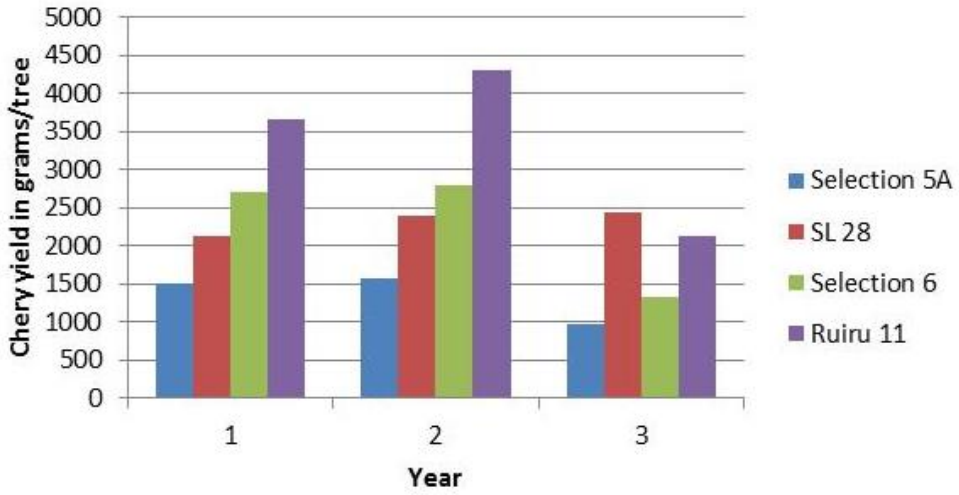

Figure1. Cherry yield in grams/tree at CRI-Kisii

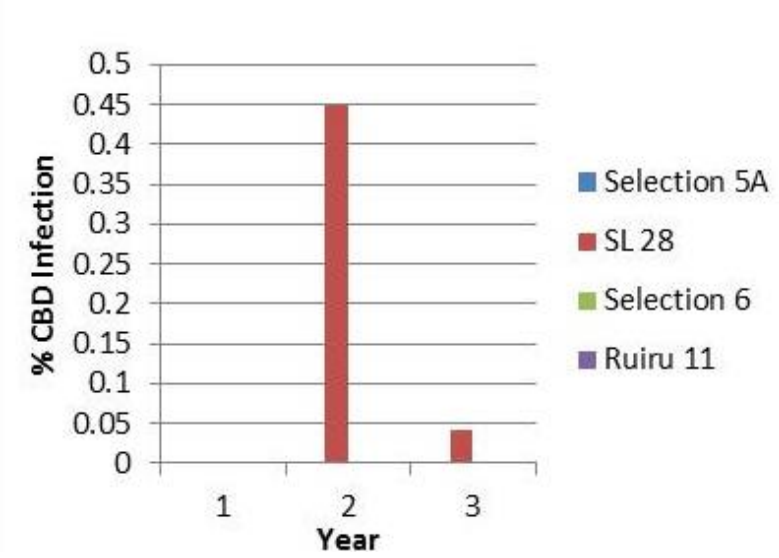

Figure 2. CBN infection at CRI-Kisii

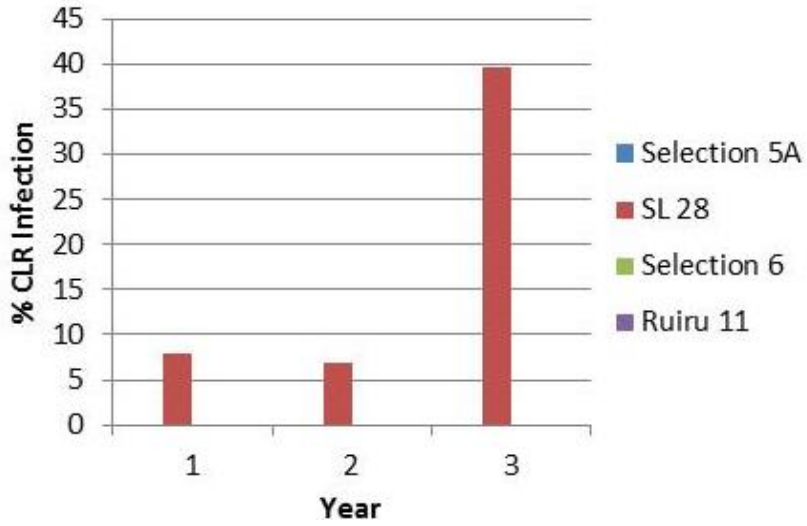

Figure 3. CLR infection at Cri-Kisii

that a combination of growth parameters in addition to one or two years yield data offers an accurate estimate of yield potential of a variety. To determine the yield potential of the Indian accessions, measurements on growth and crop bearing parameters were supplemented with actual yield records for a period of three years. Of the two Indian accessions, it was only Selection 6 that appeared to be promising in yield as compared to the Kenyan cultivars. The yield of Selection 5A was inferior.

The yield of Ruiru 11 for the first two consecutive years at CRI-Kisii were higher than all the three varieties under trial. Although the Indian accessions were resistant to CBD and CLR, their yield potential may be inherently low or they may not be adapted to the coffee growing conditions in Kenya. SL 28 has the potential to record high yields but CLR infection at CRI-Kisii may have contributed to the low cherry weight. Observations made over the three year period indicate that there was depressed yield in year 3 compared to years 1 and 2. The biggest yield decline was observed on Ruiru 11 and Selection 6 whose production in years 1 and 2 were higher than SL 28 and Selection 5A. It has been observed that high production in coffee may be followed by low yields in subsequent years unless a proper regime of nutrition is effected to even out the production.

The phenomenon of biennial bearing was even more pronounced at Machakos ATC (Figure 4) where yields in year 2 were depressed after a heavy crop in year 1 but

Table 3. Analysis of Variance results for yield and CLR scores at Machakos ATC.

Source	DF	Yield		CBD	
		Mean Square	Probability	Mean Square	Probability
Reps	2	1141727.70	0.16^{NS}	0.0597829.00	0.16^{NS}
Main effects					
Genotype	3	825206.70	0.00***	1.6389632.00	0.00**
Year	2	27300420.00	0.00***	0.0789484.00	0.09^{NS}
Interactions					
Genotype × Year	6	3164806.70	0.00***	0.0789484.00	0.04*
Error	22	574183.30		0.0296226.00	

Key:
NS = Not Significant
* = Significant at P ≤ 0.05
** = Significant at P ≤ 0.01
*** = Significant at P ≤ 0.001

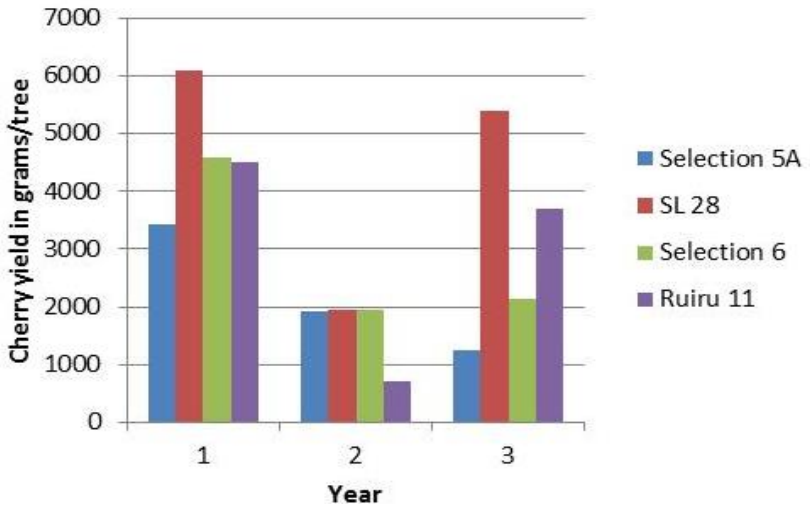

Figure 4. Cherry yield in grams/tree at Machakos ATC

the trees tended to recover again in year 3 especially for SL 28 and Ruiru 11. There was no CBD infection at Machakos ATC because the climatic conditions are not favourable for the disease. However CLR infection was evident on susceptible SL 28 but the effect on yield was minimal.

CONCLUSION

The yield potential of Indian selections were found to be lower than the standard Kenyan cultivars. Selection 6 appeared to be promising in yield. However, both accessions were outstanding in resistance to CLR which was only comparable to the resistant Ruiru 11 variety. Inheritance studies to determine the nature of resistance to CLR operating in the Indian accessions is necessary to determine if they are different from those operating on Ruiru 11. This may provide an opportunity to deploy the genes in the Kenyan varieties as a means of broadening the genetic base of resistance to CLR and to counteract the emerging races of the rust pathogen.

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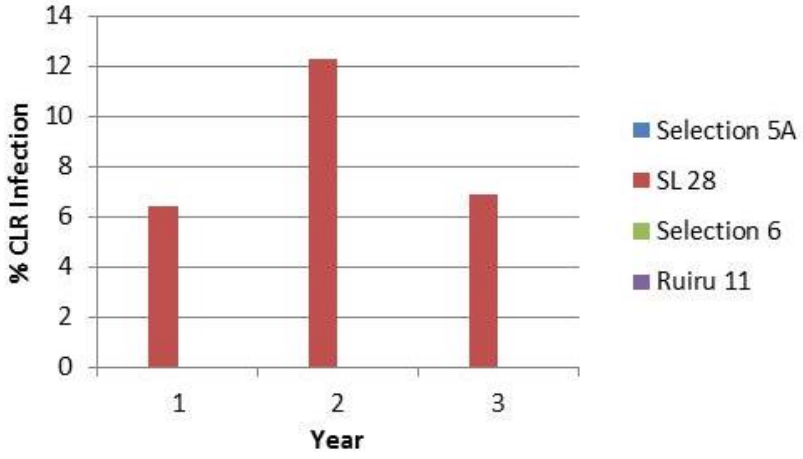

Figure 5. CLR Infection at Machakos ATC

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