Coffee Leaf Rust Epidemics (*Hemileia vastatrix*) in Montane Coffee (*Coffea arabica* L.) Forests in Southwestern Ethiopia

Chala Jefuka[1]*, Chemeda Fininsa[2], Girma Adugna[1] and Holger Hindorf[3]

[1] Jimma Agricultural Research Center, P O Box 192, Jimma, Ethiopia
[2] School of Plant Sciences, Haramaya University, P O Box 138, Dire Dawa, Ethiopia
[3] INRES-Phytomedizin, University of Bonn, Germany

Abstract: Coffee *(Coffea arabica* L.) is native to southwestern Ethiopia growing as understory of the rainforests that harbor huge floral and faunal diversities. Besides drastic reduction in the forest cover and low average yield, the crop is attacked by several diseases among which coffee berry disease, coffee wilt disease and coffee leaf rust caused by *Colletotrichum kahawae, Gibberella xylarioides* and *Hemileia vastatrix*, respectively, are the major fungal diseases contributing to reduced yield in the country. The epidemics of coffee leaf rust (CLR) was monitored between July 2007 and April 2008 in Bonga, Berhane-Kontir and Yayu montane coffee forest populations of southwest Ethiopia to determine the incidence and severity of CLR and its seasonal variation in the forest coffee populations and their reaction to leaf rust in the natural habitat. Thirty coffee trees were selected from each forest (three sites within a forest) coffee population to record incidence (percent rusted leaves), severity (percent leaf area damaged) and sporulated lesion density (number of lesion per leaf, SLD) from selected six branches per tree. An average of 10-12 leaves per branch was considered to determine each disease parameter. The data were analyzed using nested design (tree under location) using SAS statistical package. The occurrence of CLR significantly varied with locations and seasons. Overall mean incidence of 31.1, 21.4 and 7.9 and SLD of 2.7, 1.8 and 0.86 occurred in Yayu, Berhane-Kontir and Bonga montane coffee forest populations, respectively. Leaf rust was low (13.9%) in July 2007 and high (29.6%) in January 2008. Significant variation observed among each coffee tree within a location and season significantly interacted with both location and coffee trees within a location. The mean rust incidence varied from 0.36 to 18.5% in Bonga, 1.8 to 49% in Berhane-Kontir, and 11.8 to 62.6% in Yayu forest coffee populations. The corresponding severity ranged from 0.08 - 1.2%, 0.24 - 1.7% and 0.91 - 3.3% whereas the SLD varied from 0.08 - 1.9, 0.33 - 3.65 and 1.5 - 5.9% in that order. The observed heterogeneity of forest coffee populations to leaf rust in the field under native agro-ecology provides an opportunity to develop resistant varieties among the enormous forest coffee genetic resources and at the same time calls for strategic multi-site in situ conservation to rescue and maintain the present genetic variation and enhance co-evolutionary processes. The selected forest coffee trees that showed promising results should be further investigated for their possible value for future utilization. The location-season and coffee tree-season interaction effects necessitate characterization of *Hemileia vastatrix* races prevalent at each location and insist strategic variety development for contrasting environments.

Keywords: Coffee Leaf Rust; Ethiopian Coffee; Epidemics; *Hemileia Vastatrix*; Incidence; Seasonal Variation; Severity

1. Introduction

Coffee (*C. arabica* L.) is the only tetraploid species representing the genus *Coffea* and native to semi-humid highland forests of southwest Ethiopia (Sylvain, 1958; Melaku, 1982; Wintgens, 2004). This crop is dominantly grown traditionally under rainfed in Afro-montane rainforest coffee belt generally categorized into sub humid hot to warm low to mid highland mountains/SH_{1-7}; sub humid tepid to cool mountains/SH_{2-7}; humid-hot to warm low to mid highland mountains/H_{1-7}; and humid tepid to cool highland mountains/H_{2-7} (Paulos and Tesfaye, 2000).

The crop is produced under forest, semi-forest, garden and plantation production systems which account for about 10, 35, 50 and 6% of the total production in the country (Workafes and Kassu, 2000; Alemayehu *et al.*, 2008; MoARD, 2008). Recent report indicated that Ethiopia is the fifth largest coffee producer in the world after Brazil, Vietnam, Indonesia and Colombia (Sette, 2011). It remains as a backbone of Ethiopian economy contributing 41% of foreign exchange, sustaining more than 1 million farming household, absorbing 25% employment opportunity and 10% of government revenue (Petit, 2007; MoARD, 2008). Moreover, its genetic resources contained in the rainforests were valued to around 1458 and 420 million USD at 5 and 10% discount rate, respectively (Hein and Gatzweiler, 2005).

The crop is vulnerable to several diseases among which coffee berry disease caused by C*olletotrichum kahawae* Waller and Bridge, coffee wilt disease caused by *Gibberella xylarioides* Heim and Saccas and coffee leaf rust caused by *Hemileia vastatrix* Berk. and Br., are the major fungal diseases in Ethiopia. Coffee leaf rust (CLR) is one of the most important diseases of *C. arabica* in the world (Kushalappa and Eskes, 1989). It belongs to the family of Pucciniaceae in the order of Uredinales of the class Basidiomycetes. The genus has unknown pycnidial and aecidial stages and only the dikaryotic uredospores are responsible for the disease development (Kushalappa and Eskes, 1989). The pathogen exists in different physiologic groups and over 40 different races have been identified all over the world so far (Muller *et al.,* 2004). Among these, five physiologic races were reported to exist in Ethiopia (Meseret *et al.*, 1987).

The uredospores germinate in 2-4 hours under optimum conditions (22 ^{0}C and 100% RH) and complete the penetration process within 24-48 hours. Since the spores germinate only in the presence of free water, epidemics are prevalent during the wet season. Wind is responsible for the long distance dispersal while rain is

*Corresponding author. E-mail: cjefuka@gmail.com

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important for dissemination of the disease within the coffee canopy (King'ori and Masaba, 1994). The pathogen survives primarily as a mycelium in the living tissues of infected leaves.

The disease has existed in Ethiopia for long time without ravaging *C. arabica* plantations as in other countries. The long-term coexistence of coffee and rust (Eskes, 1989), high genetic diversity and high level of resistance (Van der Graaff, 1981), low average productivity associated with shade and existence of antagonistic biological agents might have maintained rust at low level. Meseret (1996) evaluated large number of coffee accessions including coffee berry disease (CBD) resistant selections and reported existence of partial resistance to CLR. Similarly, Girma and Chala (2009) tested large number of Arabica coffee collections for resistance to CLR and reported existence of significant differences among the collections. Despite the availability of effective fungicides and resistant varieties for the control coffee leaf rust, it may still cause losses varying between 10 and 40% in different countries (Silva *et al.,* 2006).

Although the Ethiopian montane rain forests are hosting large gene pool of *C. Arabica,* they are under severe threat of extinction. According to recent reports, the forests are disappearing at an alarming rate of 100,000-120,000 hectare (ha) per annum (Simayehu *et al.*, 2008). Such overwhelming Arabica forest coffee destruction, and its narrow genetic basis outside Ethiopia, has initiated an *in situ* coffee conservation accompanied with its characterization for agronomic, breeding, and disease and insect pests resistance traits. Subsequently, the reaction of forest coffees to coffee berry and wilt diseases (Arega, *et al.*, 2008), the insect pest dynamics and their natural enemies in the forest (Chemeda, 2007) and ecophysiological aspect (Taye and Burkhardt, 2008) of forest coffee populations were evaluated. However, the forest coffee has not been studied in detail for its reaction to leaf rust to develop resistant varieties as well as to focus on conservation of wide genetic base of the forest areas. Moreover, knowledge of seasonal occurrence of CLR is essential for developing effective disease management tactics, establishing selection strategy, and identifying an optimum time of assessment for genotype screening under field conditions. Data based on epidemiological studies are useful to develop effective management strategies. However, only limited work has been done so far in the forest coffee-rust pathosystem. Taking these recurring situations into consideration, the specific objectives of this study were to determine the incidence and severity of CLR in the forest coffee and to describe the seasonal variation of CLR in the forest coffee populations.

2. Materials and Methods

2.1. Study Area Description

Studies on coffee leaf rust (CLR) were conducted in Berhane-Kontir (Sheko District), Bonga (Gimbo District), and Yayu (Yayu District) montane forest coffee populations found in southwest Ethiopia. Both the Berhane-Kontir and Bonga forests are found in the Southern Nations, Nationalities and Peoples' Region (SNNPR) in Bench-Maji and Kaffa Zones, respectively, while the Yayu forest is found in Illubabor Zone of the Oromia Regional State (Table 1; Figure 1). The forests form part of national coffee forest protection priority areas among which about 20,000 ha of Berhane-Kontir, 18,600 ha of Yayu and 5,500 ha of Bonga forest were identified for biodiversity and forest coffee conservation in the country (Paulos and Demel, 2000). The forest soil is clay loam in texture. These rainforests are situated at an altitude range between 1100 and 1870 meters above sea level (masl) with an average annual temperature varying from 19.1 to 22 ^{0}C and annual rainfall from 1472-1599 mm (EMSA, 2007) (Table 1).

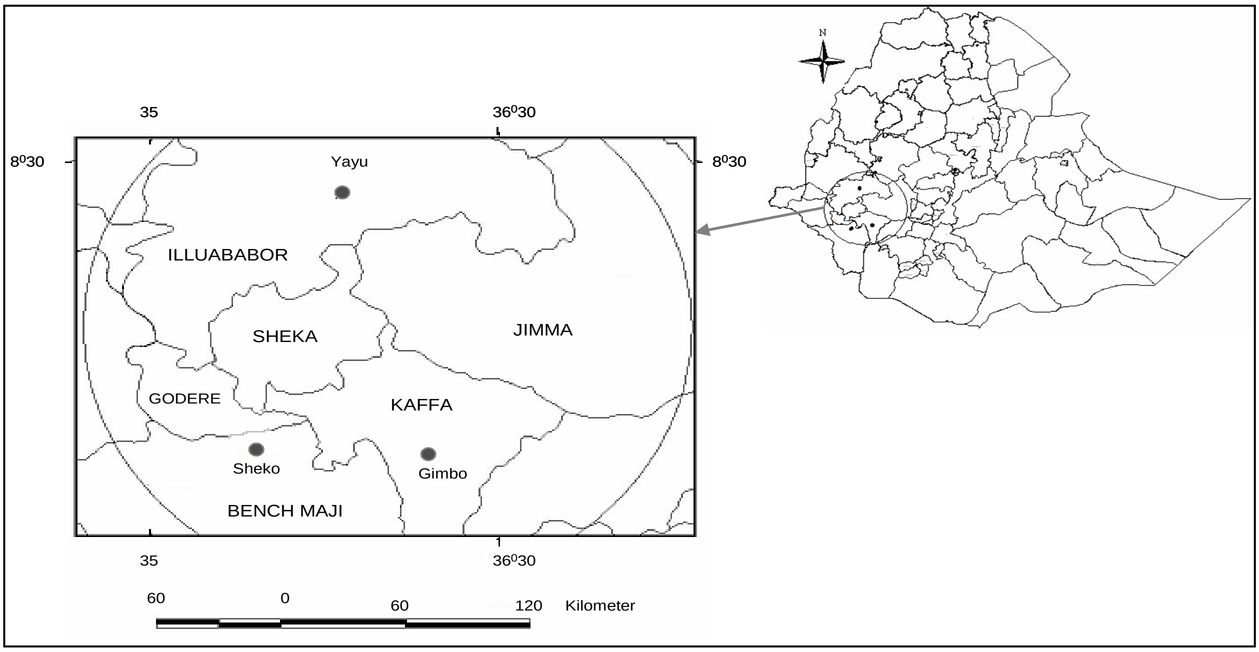

Figure 1. Map of Ethiopia showing coffee leaf rust study sites (●) in 2007 and 2008 in southwestern Ethiopia.

Table 1. Description of coffee leaf rust disease study sites in the montane coffee forest populations of southwestern Ethiopia.

Study area	Bonga[a]	Berhane-Kontir[a]	Yayu
Region	SNNPR	SNNPR	Oromia
Zone	Kaffa	Benchi-Maji	Illuababor
District	Gimbo	Sheko	Yayu
Coordinate (N)	7° 17´-7° 20´	7° 04´-7° 07´	8° 23´
(E)	36° 03´-36° 13´	35° 25´-35° 26´	35° 47´
Altitude (masl)	1620-1870	1110 -1180	1490-1497
Annual rainfall (mm)	1560.7	1535.4	1599
Mean temperature (^{0}C)	19.2	22.0	20.6

Note: a = Southern Nations, Nationalities and Peoples' Region

2.2. Assessment of Coffee Leaf Rust in Forest Coffee Populations

Survey of CLR disease was conducted in July 2007 (beginning of the rainy season, *Kiremt*), October 2007 (beginning of the dry season, *Tseday)*, January 2008 (middle of the dry season, *Bega*) and April 2008 (beginning of the short rainy season, *Belg)* to determine the seasonal variation of leaf rust in the Berhane-Kontir, Bonga and Yayu montane forest coffee populations. Three specific fields of about 50 m x 50 m which were assumed to represent each forest coffee populations were selected from each of these montane forest coffee populations based on accessibility, coffee tree uniformity and information on previous work on CBD and coffee wilt disease (CWD). A sample size of 10 trees with relatively uniform age were systematically selected at a distance of about 6-8 m interval within the sampling plot from each forest coffee site yielding a total of 30 coffee trees from each location. A sample size consisting of all the leaves in four simple branches of 4-6 plants was reported to have the least coefficient of variation (CV, %) in a plot of 100 plants (Kushalappa, 1989) and similarly, Meseret (1996) used five trees per site as determined with low coefficient of variation. Based on these facts, three pairs of branches each pair representing upper, middle and lower canopy layers of the coffee plant were selected and marked with label to assess CLR incidence, severity and sporulating lesions per leaf on a total of 270 pairs of branches in the three locations.

Rust incidence expressed in percentage was determined as the number of diseased leaves per branch. Similarly, rust severity as proportion of leaf area rusted was estimated on all leaves of sampled branch using diagrammatic scale developed by Kushalappa and Chaves (1980). In the diagrammatic scale, 1, 3, 5, 7 and 10 indicates 1, 3, 5, 7 and 10% of leaf area rusted, respectively. Any rust severity on the leaves was estimated by making a cumulative count of each sporulating lesion area per leaf (Figure 2) following the scale of Kushalappa and Chaves (1980). The sporulating lesion density (SLD) was determined as the number of sporulated lesions per infected leaves.

The data were summarized on excel spreadsheet software and the mean rust incidence, severity and SLD were analyzed for each forest coffee tree. Analysis of variance (ANOVA) was performed using single stage nested design (tree was nested under location) and time of rust assessment made (season) was considered as cross effect over the locations. Multiple range comparison tests were applied wherever appropriate using the Fisher protected significant difference test (LSD) at a probability level of 5%. The statistical analysis was performed using SAS statistical package (SAS, 2001).

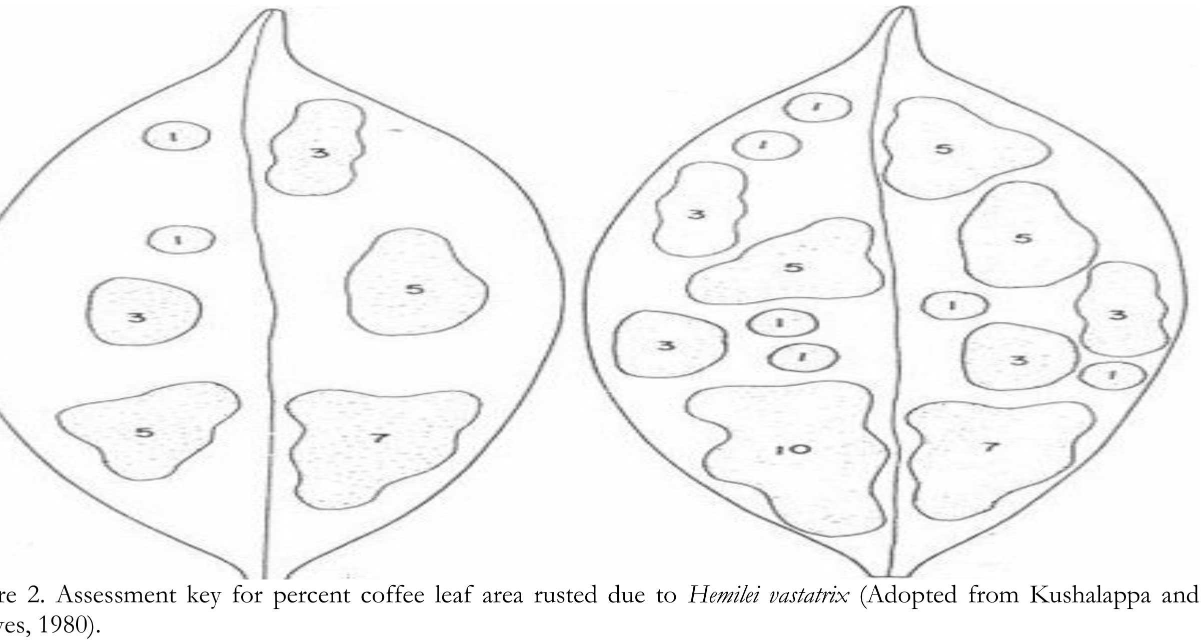

Figure 2. Assessment key for percent coffee leaf area rusted due to *Hemilei vastatrix* (Adopted from Kushalappa and Chaves, 1980).

3. Results

Coffee leaf rust assessment made in three southwestern Ethiopian montane coffee forest populations revealed its presence in all fields assessed differing in magnitude with time (season) and location of the forest coffees. A significantly (P < 0.001) high (31.1%) rust incidence was recorded in Yayu followed by Berhane-Kontir (21.4%) and Bonga (7.9%) forest coffee populations. The mean rust incidence varied from 18.2-46.2 in Yayu, 7.3-36.6 in Berhane-Kontir and 5.9-9.1% in Bonga between July 2007 and April 2008 (Figure 3). The overall incidence was high (29.6%) in January and April (22.7%) in Yayu and Berhane-Kontir, respectively, while it was low in July (13.9%) in Berhane-Kontir and October (14.3%) in Yayu. Rust incidence was consistently higher in Yayu and Brerhane-Kontir and lower in Bonga forest during all the four months (Figure 4).

The reaction of coffee trees to CLR infection within a location was significantly different (P < 0.001). The mean rust incidence varied from 0.36-18.5% in Bonga, 1.8-49% in Berhane-Kontir, and 11.8-62.6% in Yayu forest coffee populations (Table 2). There was no coffee tree that showed greater than 20% rust incidence in Bonga. On the other hand, there were only three coffee trees (Y2, Y14, and Y27) that had less than 19% rust infection among the evaluated Yayu forest coffee populations (Table 2). Coffee tree infection by CLR varied from among months and some forest coffee trees had as high as 69% rust incidence in January 2008 but less than 3% incidence in July 2007. Similarly, some coffee trees had high incidence (40%) in October 2007 and low rust (10%) in July 2007 (data not shown). This subsequently resulted in significant interaction and variation with both coffee tree and forest locality.

Significant difference (P < 0.001) was observed in the level of SLD across forest coffee populations as well as selected months. A mean SLD value of 2.66, 1.79 and 0.86 were calculated for Yayu, Berhane-Kontir and Bonga, respectively (Table 2) but it ranged from 2.2-3.5 in Yayu, 1.4-2.4 in Berhane-Kontir and 0.45-1.1 in Bonga forest coffee populations between July 2007 and April 2008. The SLD was consistently higher in Yayu and Brerhane-Kontir and lower in Bonga forest during all the four selected months (Figure 4). Each individual tree also varied with amount of SLD accommodated per tree per leaf and ranged from 0.08-1.90, 0.33-3.65 and 1.50-5.90% in Bonga, Berhane-Kontir and Yayu forest coffee populations, respectively (Table 2).

The pattern of CLR severity in the forest coffee population essentially followed SLD as only the visible sporulating lesions were accounted in the severity estimation. The mean rust severity varied from 0.08-1.20% in Bonga, 0.24-1.70% in Berhane-Kontir and 0.91-3.30% in Yayu forest coffee populations (Table 2) while an overall rust severity of 0.55%, 0.99 and 1.40 were calculated for the respective forests coffee populations (Table 2 and Figure 3).

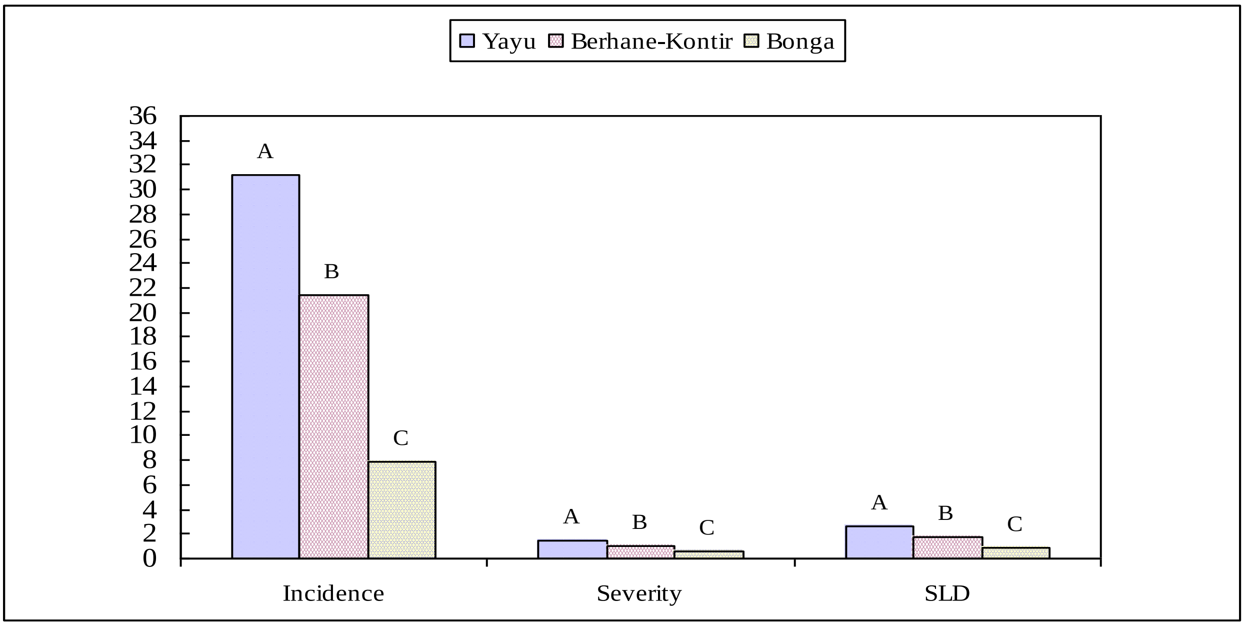

Figure 3. Coffee leaf rust incidence (%), severity (%) and sporulation lesion density (SLD) in three montane forest coffee populations of southwestern Ethiopia (July 2007-April 2008). Values were mean of four assessments (July 2007, October 2007, January 2008 and April 2008) for each disease parameter at each location. Bars with the same letters within each disease parameter are not significantly different according to LSD at P = 0.05.

Table 2. Coffee leaf rust incidence (I), severity (S) and sporulated lesion density (SLD) in three montane coffee forest populations (B, BK and Y) of southwestern Ethiopia from 2007 - 2008.

	Bonga (B)				Berhane-Kontir (BK)				Yayu (Y)		
Tree	I	S	SLD	Tree	I	S	SLD	Tree	I	S	SLD
B1	6.65	0.48	0.58	BK1	13.49	0.71	1.15	Y1	62.55	3.34	5.93
B2	18.52	0.99	1.35	BK2	23.11	0.71	1.23	Y2	18.51	1.59	3.60
B3	6.77	0.59	0.89	BK3	32.07	1.30	2.27	Y3	21.71	1.12	1.87
B4	5.60	0.45	0.58	BK4	20.31	1.27	1.74	Y4	30.87	1.36	2.58
B5	4.74	0.34	0.48	BK5	6.38	0.40	0.55	Y5	28.14	1.19	2.47
B6	10.70	0.59	0.88	BK6	12.38	0.90	1.25	Y6	38.16	1.30	2.60
B7	7.76	0.40	0.70	BK7	11.06	0.67	1.09	Y7	29.14	1.25	2.11
B8	8.00	0.89	1.41	BK8	24.67	0.88	1.34	Y8	62.61	2.08	4.14
B9	11.27	0.66	1.00	BK9	25.68	1.02	2.00	Y9	19.79	1.96	3.23
B10	6.20	0.45	0.82	BK10	1.80	0.24	0.33	Y10	27.18	0.96	1.76
B11	8.45	0.77	1.19	BK11	16.73	0.87	1.35	Y11	30.01	1.34	2.17
B12	8.70	0.46	0.74	BK12	17.58	0.90	1.51	Y12	26.86	0.92	2.06
B13	14.29	0.73	1.09	BK13	19.39	0.95	1.44	Y13	35.98	1.45	3.12
B14	7.03	0.59	0.93	BK14	16.46	0.96	1.45	Y14	17.04	1.31	1.96
B15	13.54	0.81	1.32	BK15	3.36	0.24	0.34	Y15	25.38	1.61	2.79
B16	7.15	1.15	1.90	BK16	29.72	0.92	1.64	Y16	34.74	1.30	2.71
B17	10.25	0.52	0.98	BK17	7.78	1.06	1.70	Y17	33.61	0.91	1.70
B18	9.28	0.44	0.65	BK18	19.98	0.88	1.36	Y18	24.99	0.83	1.50
B19	7.88	0.50	0.88	BK19	7.27	0.68	1.13	Y19	35.21	1.19	3.15
B20	16.54	0.97	1.68	BK20	13.14	0.67	1.05	Y20	22.86	1.06	2.19
B21	4.30	0.66	1.08	BK21	16.12	1.10	1.88	Y21	27.52	1.06	1.96
B22	1.12	0.20	0.31	BK22	28.86	1.23	2.42	Y22	50.38	1.76	3.59
B23	3.19	0.38	0.56	BK23	45.90	1.52	3.36	Y23	35.99	2.05	3.18
B24	1.27	0.18	0.24	BK24	48.34	1.73	3.81	Y24	33.69	2.02	3.97
B25	10.70	0.47	0.72	BK25	47.99	1.49	2.89	Y25	34.05	1.36	2.33
B26	1.14	0.18	0.23	BK26	15.04	1.28	2.98	Y26	27.21	1.04	1.86
B27	8.37	0.45	0.63	BK27	27.50	1.41	2.96	Y27	11.87	0.91	2.04
B28	0.36	0.08	0.08	BK28	20.33	1.23	2.30	Y28	26.70	1.09	2.14
B29	3.25	0.39	0.52	BK29	20.60	0.89	1.48	Y29	23.01	1.13	2.29
B30	14.34	0.73	1.49	BK30	49.07	1.67	3.65	Y30	38.00	1.37	2.75
Range	0.36-18.5	0.08-1.2	0.08-1.9		1.8-49	0.21 - 1.7	0.33-3.65		11.8-62.6	0.91- 3.3	1.15-5.9
Mean	7.91	0.55	0.86		21.40	0.99	1.79		31.12	1.40	2.66
LSD(0.05)	11.65	0.697	1.28		11.65	0.697	1.28		11.65	0.697	1.28

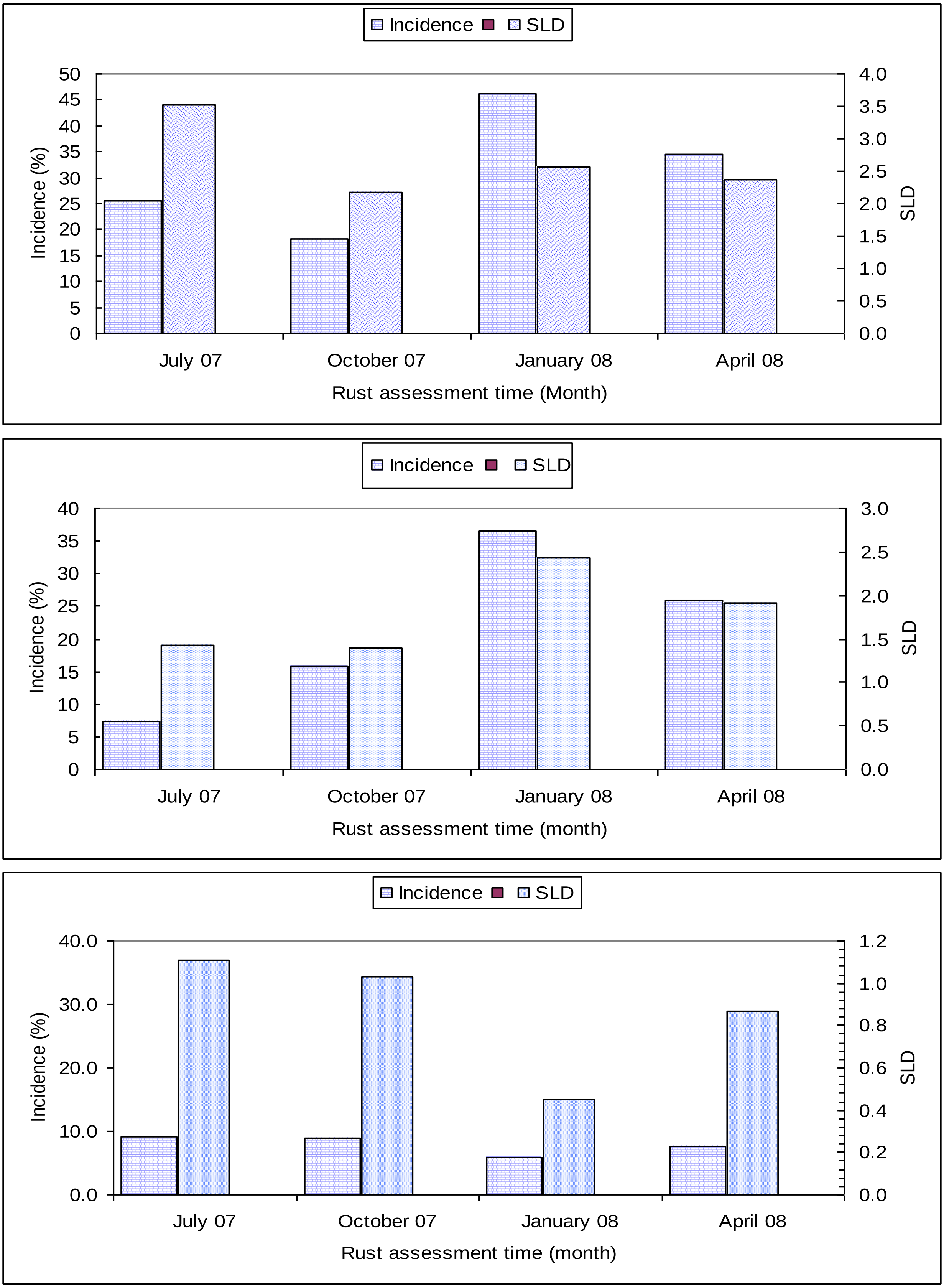

Figure 4. Coffee leaf rust incidence (I) and sporulated lesion density (SLD) in Yayu (a), Berhane-Kontir (B) and Bonga (c) over four selected months during 2007 and 2008.

4. Discussion

4.1. Coffee Leaf Rust in the Forest Coffee Populations

The occurrence of CLR varied from location to location and its incidence was high in Yayu followed by Berhane-Kontir and Bonga forest coffee population. Arega *et al.* (2008) also reported higher rust incidence in Yayu than in Bonga forest coffee population. These variations across forests were attributed to human activities, altitude and environmental gradients across the location. Inadvertent human activities such as transformation of the intact natural forest to semi-forest production system for improving productivity and coffee farmland expansion, exclusive thinning of over story trees, slashing of weeds and shrubs (at least twice a year in Berhane-Kontir), adjusting coffee tree population using self-regenerated coffee trees and seedlings might have increased the transmission and contact of the rust pathogen within the forest coffee trees. Soto-Pinto *et al.* (2002) reported significantly higher rust incidence in plots where paths were present than plots without paths in the forest. Higher rust incidence predominantly occur in plantation and garden than in forest coffee (Meseret, 1996; Eshetu *et al.,* 2000) and intensive production system (Avelino*,* 2006) implying variation in rust intensity with coffee management practices.

The low SLD in the Bonga montane forest coffee population is mainly due to poor light penetration into the dense canopy cover of forest trees and minimal disturbance of the intact forests. This resulted in lower infection frequency and lesion expansion on the leaves that subsequently resulted in low SLD and subsequent rust severity. Thus, management practices and variable crop bearing potential from location to location and tree canopy stature might have influenced leaf rust. It is assumed that higher yields and high light intensity predispose coffee plants to rust infection (Eskes, 1989). According to Avelino *et al.* (2004) and Avelino (2006), both rust and yields did not reach high level under dense shade indicating that shades reduce leaf rust through keeping yields at low levels.

The differences in rust incidence, severity and SLD across the forest coffee populations were also related to variation in altitude. Studied fields in Yayu and Berhane-Kontir forest coffee populations were situated at an altitude less than 1200 masl, whereas the Bonga forest fields were found between 1620 and 1870 masl. Simple linear correlation analysis based on data set in this report revealed inverse relationship between rust incidence and altitude but not significant. Nevertheless, the effect of altitude on the development of CLR was reported by several researchers (Kushalappa, 1989; King'ori and Masaba, 1994; Brown *et al.,* 1995; Meseret, 1996). Rust incidence decreased with increase in altitude and, at higher altitudes, the low night temperatures followed by still low day temperatures resulted in a longer latent period and slower epidemic, while it hasten rust development in low altitude belts.

The observed high location and seasonal variation and interaction realistically discerned the difference of each coffee tree from location to location grown under diverse environment. It also indicates existence of variation in susceptibility of coffee trees to leaf rust over months, which may be due to variation in conduciveness of environmental factors that directly or indirectly influence leaf rust development, effect of leaf age, and variation in expression of susceptibility to leaf rust.

4.2. Seasonal Variation of Coffee Leaf Rust

The seasonal variation of rust in the forest could be categorized into two major distinct seasons based on crop phenology and pattern of rainfall prevailed in the forest coffee populations as there are only two main distinct (dry and wet) seasons in Ethiopia, namely winter and summer which are dry and wet seasons, respectively. The spring (onset of short rains) and the autumn (onset of dry period) are indistinctively linked to the formers as a transition periods. Rust was initiated during the onset of rain and further amplified in subsequent rainy season and attained highest values at later stage corresponded to the onset of dry season in the forests.

The occurrence of mean monthly temperature varying from 17.7-18.4 ^{0}C in Yayu and 20.1-20.7 ^{0}C in Berhane-Kontir and relative humidity of 79.9-82.7% in Yayu and 79.7-88.7% in Berhane-Kontir that prevailed within the forest coffee canopy during November 2007 to January 2008 might have favored CLR development in both locations (Table 3). It has been reported that rapid development of rust pustules and heavy sporulations are intensified by sunny warm weather conditions accompanied by intermittent rains (Muthappa *et al.*, 1989). The seasonal fluctuation of rust severity observed in the study areas is in agreement with previous reports where maximum leaf rust occurred in November to December corresponding to the onset of dry season and harvesting time (Meseret, 1996; Eshetu *et al.,* 2000). Moreover, low rust incidence has been reported for the period from June to September that increased to high level during November to March in the forest coffee populations (Arega *et al.*, 2008).

Furthermore, abscission of senescent leaves, sustaining of infected leaves over an extended period serving as source of uredospores, and insignificant leaf formation in dry season might have drastically elevated rust in the relatively dry period. It is reported that both older and newly formed young leaves are resistant to rust infection, whereas young leaves of an intermediate age are susceptible to rust (Eskes, 1983; 1989; Meseret, 1996). Younger leaves are found to be immune to infection due to absence of well-developed stomata (McCain and Hennen, 1984). On such leaves, the fungus fails to recognize stomata for infection to take place (Coutinho *et al.*, 1994). Besides, the hydrophobic nature of young leaf surface may hinder uredospore germination and penetration processes.

Coutinho *et al. (*1994) observed no spore production on older leaves. Similarly, the inhibition of *H. vastatrix* uredospore germination has been reported to take place due to host metabolites induced by non-pathogenic fungi (Martins *et al.,* 1986) and endophytic bacteria (Shiomi *et al.*, 1998) as well as hyperparasitization by *Verticillium* spp. (Meseret, 1983; Eskes, 1989; King'ori and Masaba, 1994). The longer lifespan of forest coffee leaves grown under shade in undisturbed forests are privileged to accommodate large populations of such resident micro-organisms that either antagonize or create antifungal environment unconducive in the phyllosphere.

Generally, coffee trees were rarely free from rust infection; rather both sporulating and non-sporulating lesions were observed with low sporulation intensity and SLD. Eskes (1983) indicated that many coffee plants in Ethiopia do not have any recognizable major resistance gene and the resistance of C. arabica to rust may be due to minor genes. These minor genes are sensitive to environmental factors, such as light intensity and temperature. In *C. canephora*, leaves grown under shade and exposed to sun showed resistant and susceptible reactions, respectively (Eskes, 1983). Significant variation in reaction to leaf rust across season in both Arabica and Robusta coffee were also reported (Eskes, 1983; Dakwa, 1987).

Table 3. Temperature and relative humidity measured within the forest coffee tree canopy at Yayu and Berhane-Kontir forest coffee populations.

	Yayu		Berhane-Kontir	
Month and year	Temperature (^{0}C)	Relative humidity (%)	Temperature (^{0}C)	Relative humidity (%)
June 2007	18.81	52.58	20.95	74.75
July 2007	18.15	73.54	20.26	77.05
August 2007	18.14	69.12	19.85	65.24
September 2007	18.43	70.42	19.92	88.37
October 2007	18.00	79.87	20.11	82.39
November 2007	18.38	82.74	20.65	79.73
December 2007	17.70	81.45	20.24	88.66
January 2008	18.84	76.76	21.01	78.18
February 2008	20.03	70.37	21.48	67.10
March 2008	20.99	68.66	21.85	73.04
April 2008	20.28	80.80	21.31	67.93
Mean	18.89	73.30	20.69	76.59

In summary, coffee leaf rust was present in all assessed forest coffee populations, but significantly varied from location to location and among months as well. The level of coffee tree infection by CLR was also significantly varied among each other indicating variability of each coffee tree from location to location and within a location in response to rust infection. The observed significant coffee tree by month interaction implied variation in conduciveness of environment for rust development over time (month). This may also emanate from the existence of quantitative variations in both host and pathogen in different environmental combinations.

The significant variation of indigenous forest coffee trees in reaction to CLR, its responsiveness to environmental instability and variation in leaf age might have synergistically induced significant forest coffee tree-environment-interaction which is little understood under natural pathosystem. In these recurring natural rust forest coffee system, coherent investigations with introduction of modifications into the natural system is suggested. The interaction effects also necessitate characterization of *Hemileia vastatrix* races prevalent at each location to persevere strategic variety development for contrasting environments. The existence of heterogeneous montane coffee forests to rust in the field under native agro-ecology is an asset to develop resistant varieties among the enormous forest coffee genetic resources and calls for strategic *in situ* conservation to rescue and maintain the present variation and encourage co-evolutionary processes.

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