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Research article

Status of *Fusarium* head blight on wheat fields in Southwestern Ethiopia

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Abstract
Status of *Fusarium* Head Blight (FHB) had thoroughly assessed on 52 soft wheat fields from 5 districts within 3 zones of Oromia, Ethiopia. The results showed FHB was 93.9% prevalent with significantly varied levels of incidences (among zones) and severity (among districts and zones). The highest incidence of 38.7 and 26.0% had been recorded in Buno-Bedele and Jimma zones. Correspondingly, the highest field-severity and FHB-index of 28.2 and 13.9% had been recorded in Buno-Bedele. Besides, the 2 mostly grown Danda'a and Digalu varieties were vulnerable to FHB sustaining 32.3 and 30.5% incidence, 21.8% and 21.7% field-severity, and 10.5% and 8.8% FHB-index. The variation in FHB intensity had mostly influenced by altitude, tillage frequency before sowing, and rainfall received during flowering to hard-dough stages. This study reveals evidence that FHB is becoming an important disease to wheat in Southwestern Ethiopia (SWE). Thus, demands an intervention to reduce its probable risk to wheat across SWE.

Keywords
FHB, soft wheat, *Triticum aestivum*

Introduction

Wheat (*Triticum* spp.) is the second most cultivated cereal crop in the globe next to rice (FAO, 2018). Ethiopia is the second-largest wheat producer next to Egypt in Africa (FAO, 2018) with a total of 4.54 million tons produced on 1.70 million hectares of land with a national average yield of 2.68 t ha^{-1} (CSA, 2017) below the global yield of 3.65 t ha^{-1} (FAO, 2018). These are due to numerous factors including biotic, abiotic, technical and socio-economic, and climatic factors (Barron et al., 2003; Liu et al., 2008; Hailu et al., 2011; Mann and Warner, 2017). Micro- and macroorganisms were the main constraints that caused crop losses in East Africa (Oerke, 2006). Among them, fungal pathogens like *Puccinia* spp., *Septoria* spp., and *Fusarium* spp. on spike are the main constraints to wheat production in Ethiopia (Hailu et al., 2011). *Fusarium* head blight (FHB) of wheat was one of the biotic stresses that obtained the biggest concern (Tesfaye and Anisimova, 2016).

FHB is the most destructive fungal disease of wheat worldwide, particularly in humid and semi-humid wheat-growing areas (Martinez-Espinoza et al., 2014; Lenc, 2015). The disease is caused by up to 19 species (Liddell, 2003). FHB pathogens infect several cereal crops including wheat, barley,

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oats, rye, corn, canary seed, and forage grasses, but wheat, barley, and maize are the most affected crops (Clear and Patrick, 2003; Kosová et al., 2009). Globally, the FHB of wheat has emerged as a major threat to global food security (Goswami and Kistler, 2004; McMullen et al., 2012). Infection of wheat kernels by FHB pathogens contributed to losses in grain yield and quality that includes poor seed germination (or blighted seedlings), shriveled kernels, reduced number of kernels per spike, low protein content in kernels, and low baking quality of wheat grains (Gärtner et al., 2008). In addition to crop losses, several *Fusarium* species can produce a range of mycotoxins in infected grains, making them unsuitable for animal and human consumption (Grabowski et al., 2012; Darwish et al., 2014).

In sub-Saharan Africa (SSA), there is a lack of information regarding the FHB epidemics and economic losses on wheat because of the underdeveloped research on the disease (Dweba et al., 2017). Particularly in Ethiopia, there is little information on FHB of wheat that reported the disease as one of the major wheat diseases at high altitude areas (Bekele, 1985), the 1988 cropping season as a scabby season with an incidence of 85% and severity of 5–80% (Bekele, 1990), FHB incidence of 47% in Ari district (Mitiku and Eshete, 2016), and mean FHB incidence and sevrity of 43.7% and 76.3%, respectively in West Shewa Zone (Abdisssa and Bekele, 2020). Besides, the disease was reported to cause yield losses of 60% and above under experimental conditions in the 1989 cropping season of Ethiopia (Snijders, 1989). Recenltly, nine *Fusarium* spp. were identified to cause FHB on soft wheat in Southwestern Ethiopia (SWE) (Kebede et al., 2020). In general, less concern was given to the FHB of wheat in Ethiopia since then. In addition, the past FHB survey efforts were not enclose SWE (particularly Jimma, Buno-Bedele, and West-Wollega zones) where wheat is grown as one of the staple food crops. These three zones donated 4.89% of hectares and 3.52% of tonnes to the total wheat production of the Oromia region, Ethiopia (CSA, 2017). Therefore, this study was aimed to assess the occurrence and extent of FHB on wheat fields across SWE.

Materials and Methods

Description of study areas

This study was conducted across SWE namely in Dedo and Seka-Chekorssa districts of Jimma zone, Bedele and Gechi districts of Buno-Bedele zone, and Begi district of West-Wollega zone as shown in Fig. 1.

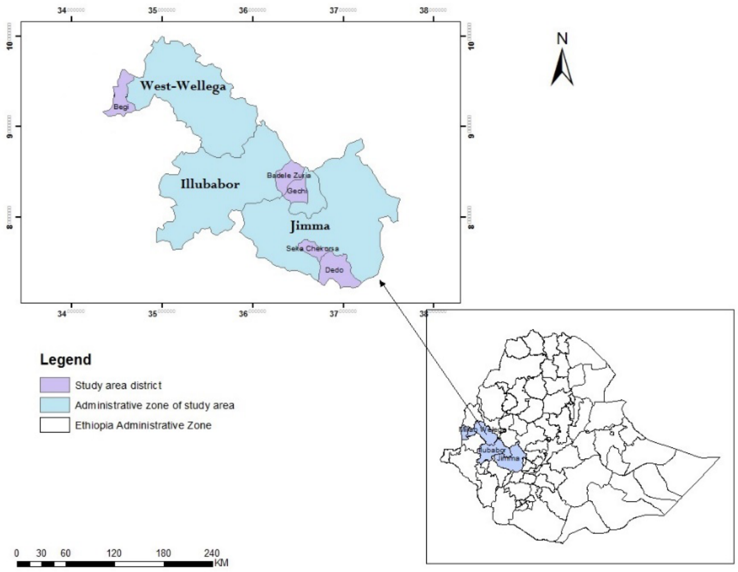

Fig. 1 - Surveyed zones and districts for FHB of wheat in SWE during 2017 cropping season.

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Sampling method and assessment of FHB disease
The purposive multistage sampling method had used to choose wheat-producing zones, districts within zones, and "*Kebeles*" (Peasant Associations) within districts. Random sampling was applied to select wheat fields in each "*Kebeles*". Potential wheat-growing districts and "*Kebeles*" were chosen by consulting zonal agricultural bureaus and the district's agricultural and natural resource offices, respectively.

A field survey of FHB had carried out in 2017 during early milk to the hard dough wheat growth stages (Zadoks et al., 1974). Within each field, disease assessment was made in four quadrats (30 × 30 cm each) along the diagonal of the field at random. All wheat spikes within the quadrat had been counted and visually examined for the presence or absence of FHB symptoms. Spikes were registered as diseased when at least single spikelet had shown typical FHB symptoms (Fig. 2).

Collected data
The incidence of FHB was recorded as the percentage of infected wheat spikes (Wegulo et al., 2008) per quadrat. Also, the severity of FHB had recorded on ten randomly chosen spikes per quadrat following the modified Horsfall-Barrett's scale (Stack and McMullen, 2011). The severity had then partitioned to field severity (the average score of all assessed wheat spikes per field) and infected head severity (the average score of only infected wheat spikes per field) (Stack and McMullen, 2011). Moreover, the FHB index (an estimate of overall disease intensity) was determined from the product of FHB incidence and field severity, divided by 100 (Wegulo et al., 2008). Finally, the prevalence of FHB across SWE had determined as a proportion of wheat fields with FHB infection out of all assessed wheat fields per district.

Agronomic practices such as previous crops, altitude, fertilizer applied, weed infestation level, source of seeds, wheat variety, planting pattern, and tillage frequency were recorded from each farm to determine the relationship with incidence and severity of FHB of wheat.

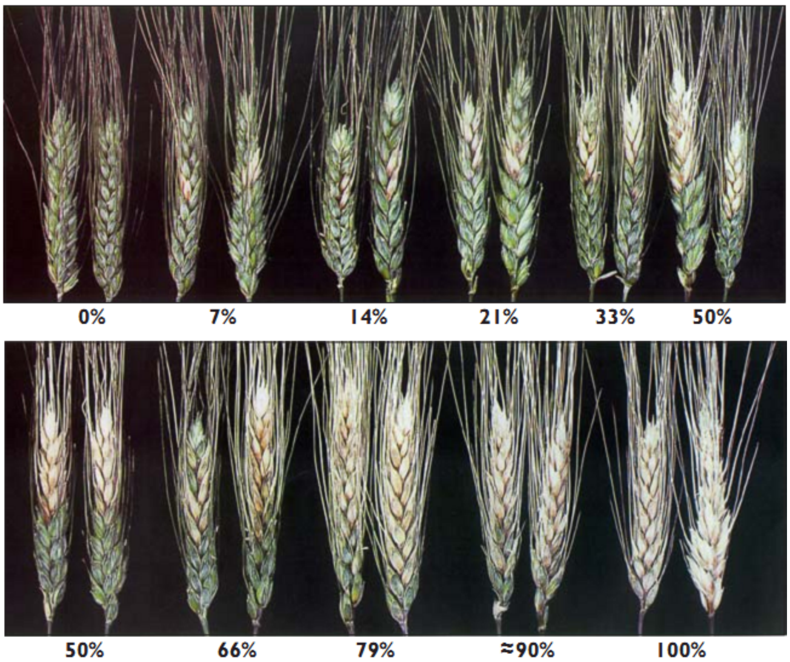

Fig. 2 - A visual FHB severity rating scale in wheat expressed in % (Stack and McMullen, 2011).

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Data analysis
The three-stage nested design procedure in SAS 9.3 statistical software (SAS, 2010) was used for the analysis of FHB Incidence, field severity, infected head severity, and FHB index data. Means were separated using the least significant difference (LSD) test at significance levels of 0.05. The associations of disease intensity with altitude and previous crop were computed using the correlation procedure of SAS 9.3 statistical software (SAS, 2010). The relationship of FHB incidence and field severity (dependent variables) with independent variables was assessed using multiple regression of SAS 9.3 (SAS, 2010). The three-stage nested model used in analyzing the data was described as follows:

$$y_{ijk} = \mu + \tau_i + \beta_{j(i)} + \gamma_{k(ij)} + \varepsilon_{l(ijk)}$$

Where: y_{ijk} is the FHB disease intensity where *"Kebeles" k* is nested within district *J* nested within zone *i*, μ is the overall mean, τ_i is the effect of the i^{th} zone, $\beta_{j(i)}$ is the effect of the j^{th} district within the i^{th} zone, and $\gamma_{k(ij)}$ is the effect of the k^{th} *"Kebeles"* within the j^{th} district and i^{th} zone, and $\varepsilon_{l(ijk)}$ is the error term.

Results and Discussion

Occurrences and extent of FHB across SWE
Fusarium head blight disease of wheat was found widespread across all inspected districts in SWE with an overall prevalence of 93.88%. At the district level, the disease was 100% prevalent in Seka-Chekorssa, Bedele, and Gechi, 91.70% in Dedo, and 80% in Begi (Table 2).

Analysis of variance showed that field severity and infected head severity of FHB had significantly differed (at $P < 0.01$) among zones, districts within zones, and "*Kebeles*" within districts and zones. In the same way, incidence and FHB index had shown a varying difference (at $P < 0.01$) among zones and "*Kebeles*" within districts and zones (Table 2).

The results indicated that FHB had registered varying incidences ranging from 0–100% in Jimma, 11.3–84.6% in Buno-Bedele, and 0–53.2% in West-Wollega zones during the 2017 main cropping season of Ethiopia (Table 2). The average FHB incidence in wheat fields was 38.69%, 26.00%, and 13.82% in Buno-Bedele, Jimma, and West-Wollega zones of the Oromia region, respectively (Fig. 3). At the district level, the higher FHB incidences of 38.7% in Gechi, and 38.6% in Bedele districts of the Buno-Bedele zone were recorded, followed by Dedo (26.6%) and Seka-Chekorssa (25.2%) districts of Jimma zone. In contrast, the lowest incidence had recorded from the Begi (13.8%) district of the West-Wollega zone (Table 2).

According to a survey conducted in 1988 cropping season of Ethiopia, FHB incidence of 0 to 35% was reported at farmer's fields in Holeta and Kulumsa areas, 0 to 56% at experiment stations, 0 to 57% at seed production fields, and 0 to 84% at state farms (Bekele and Karr, 1997). Almost after 25 years, FHB disease of wheat had reported with an incidence of 10 to 47% at farmer's fields during 2014 main cropping season in Ari district of South Omo Zone, SNNPR, Ethiopia (Mitiku and Eshete, 2016). Abdissa and Bekele (2020) reported that FHB incidence of 35–57% and severity of 52.8–90.4% in West Shewa Zone, Oromia, Ethiopia. These showed an increasing trend in FHB incidence over time in Ethiopia.

As illustrated in Fig. 3, the highest severities of FHB had recorded in the Buno-Bedele zone with field severity of 28.2%, infected head severity of 33.2%, and FHB index of 13.9%. These revealed that FHB was more severe in the Buno-Bedele zone than Jimma and West-Wollega zones. On the other hand, statistically similar field severity, infected head severity, and FHB index were recorded in Jimma, and West-Wollega zones (Fig. 3). At district levels, the severity of FHB on wheat fields was high in the Bedele and Gechi districts of the Buno-Bedele zone. The average field severity was 30.1%

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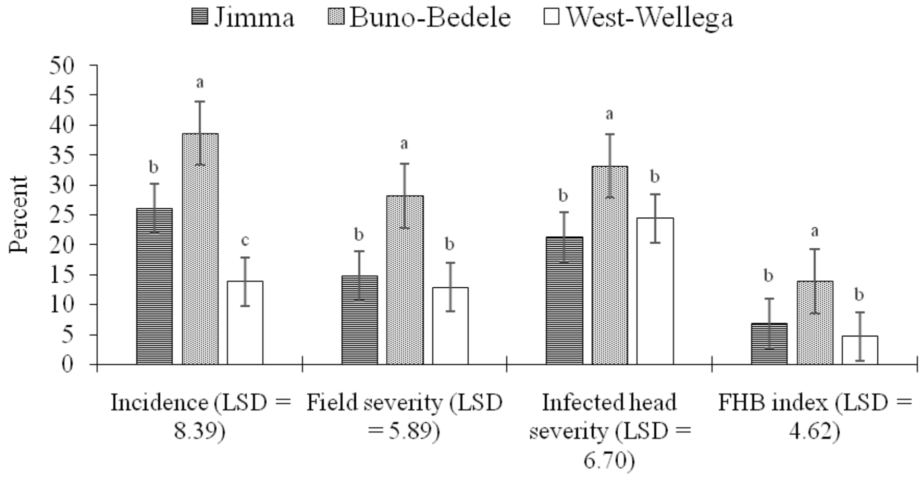

Fig. 3 - Mean incidence, field severity, and infected head severity of FHB during 2017 in three zones across SWE. Bars with a different letter for respective disease parameters are significantly different at $P < 0.01$. LSD is the least significant difference.

in Bedele and 26.9% in Gechi districts of the Buno-Bedele zone. Also, higher severity of infected heads had observed on wheat crops grown in Bedele and Gechi districts (Table 2).

On the other hand, lower and statistically similar FHB field severities had been recorded in the Seka-Chekorssa, and Dedo districts of the Jimma zone, and in the Begi district of the West-Wollega zone (Table 2). Moreover, the FHB index ranging from 4.7 to 14.7% had been recorded on wheat fields across SWE (Table 2). The disease was severe in the Gechi and Bedele districts of Buno-Bedele, where the FHB index had been recorded with a magnitude of 14.7% and 12.6%, respectively (Table 2). The use of fungicide application was suggested in North America when FHB severity is above 10% (De Wolf et al., 2003). Also, in Brazil, a 7% severity in a group of spikes at the dough stage has resulted in a significant reduction in kernel weight per spike, 1000 seed weight, and kernel infection (Casa et al., 2004). In the current study, the average field severity of 12.8 to 30.1% at district levels (Table 2) indicated that FHB disease of wheat is high in all the assessed zones that need an intervention to minimize its probable risk on wheat in SWE.

Influence of agronomic practices on FHB of wheat in SWE

Results showed that FHB incidence was highly affected by the previous crop sown in the field, tillage frequency before sowing the wheat crop, and the wheat varieties cultivated in the study area (Table 3). In the same way, FHB field severities and infected head severities were also significantly influenced by the previous crop sown in the field, tillage frequency before sowing the wheat crop, the grown wheat varieties, and altitudes (agro-ecologies). Also, FHB field severity and infected head severity was affected by weed infestation levels and sowing pattern, respectively (Table 3).

As indicated in Table 3, seed sources such as AGP-II, Cascape project, local co-operative association, and agricultural offices were found to contribute significantly to the occurrence and severity of FHB disease of wheat across the three zones in SWE. The higher incidences had been obtained from wheat fields sown by seed provided by AGP-II (47.7%), Cascape project (40.9%), and local co-operative association (36.2%). Whereas higher FHB field severity and infected head severity were registered in wheat fields sown by seeds provided by AGP-II (36.4%), and the Cascape project (27.9%). Also, wheat seeds provided by agricultural offices had attributed to higher infected head severity in the study area (Table 3). These might indicate the existence of varied infection levels of seed by FHB pathogens. Seed-borne pathogens cause enormous crop losses by attacking seedlings, and kernel

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shriveling (Kubiak and Korbas, 1999; Gärtner et al., 2008). Therefore, the use of *Fusarium*-free wheat seeds as a seed source prevents the entry of *Fusarium* inoculum into the wheat field.

This study revealed that the preceding crops such as finger millet, wheat, maize, tef, and soybean were positively correlated to the occurrence and severity of FHB disease of wheat in Jimma, Buno-Bedele, and West-Wollega zones of Oromia region, Ethiopia. The higher incidences were recorded from wheat fields previously planted by finger millet (53.2%), wheat (36.2%), and maize (35.7%), followed by tef (29.1%), potato (24.01%), and soybean (14.2%). Also, higher field and infected head severities had been recorded on wheat fields previously cultivated by finger millet, wheat, and maize with values of 40.2% and 48.7%, 36.8% and 44.6%, and 26.3% and 34.1%, respectively (Table 3).

Several studies in other Countries indicated that agronomic practices such as preceding crops, crop variety, and tillage have an impact on the diversity and spread of *Fusarium* pathogens that caused FHB on wheat (Dill-Macky, 2008; Fernandez et al., 2008; Katz, 2008; Wegulo et al., 2015).

Table 1 - Nested ANOVA table for mean squares incidence and severity of FHB.

Source	Degree of freedom	FHB incidence	Field Severity	Infected head severity	FHB index
Model	47	2017.25**	1059.23**	1088.22**	580.06**
Zones	2	8645.28**	5460.81**	3857.87**	1703.43**
Districts (Zones)	2	55.41[ns]	662.33**	2012.06**	37.28[ns]
Error	175	166.90	85.10	165.70	44.05
Mean		**28.47**	**19.41**	**26.32**	**9.04**
CV (%)		**45.37**	**47.53**	**48.91**	**76.42**

[ns] not significant at $P < 0.05$; ** significant at $P < 0.01$; ANOVA = Analysis of variance

Table 2 - Altitude ranges, prevalence (%), mean incidence (%) and severity (%) of wheat scab by districts in SWE, 2017.

Districts	Altitude range of fields	Prev.	FHB incidence		Field severity		Infected head severity		FHB index	
			Range	Mean	Range	Mean	Range	Mean	Range	Mean
Dedo	2328–2613	91.7	0.0–100.0	26.6[b]	0.0–59.7	12.3[b]	0.0–59.7	16.7[c]	0.0–59.7	7.5[ab]
Seka-Chekorssa	2051–2462	100.0	7.6–44.2	25.2[b]	3.8–36.8	18.0[b]	10.7–44.6	27.3[b]	0.5–13.3	5.9[c]
Sub$_{Jimma}$	**2051–2613**	**95.8**	**0.0–100.0**	**26.0**	**0.0–59.7**	**14.7**	**0.0–59.7**	**21.2**	**0.0–59.7**	**6.8**
Bedele	1949–2009	100.0	18.0–69.8	38.6[a]	17.4–45.4	30.1[a]	22.4–50.4	37.3[a]	3.9–22.5	12.6[ab]
Gechi	2140–2269	100.0	11.3–84.6	38.7[a]	3.9–48.3	26.9[a]	9.6–49.0	30.6[ab]	0.4–38.2	14.7[a]
Sub$_{Buno-Bedele}$	**1949–2269**	**100.0**	**11.3–84.6**	**38.7**	**3.9–48.3**	**28.2**	**9.6–50.4**	**33.2**	**0.4–38.2**	**13.9**
Begi	1711–1951	80.0	0.0–53.2	13.8[c]	0.0–41.6	12.8[b]	0.0–53.7	24.4[bc]	0.0–21.3	4.7[c]
Overall	**1711–2613**	**93.9**	**0.0–100.0**	**28.5**		**19.4**		**26.3**		**9.0**
LSD				**10.3**		**7.2**		**8.2**		**5.7**

Mean values in a column with different letters are significant at $P < 0.05$; CV = coefficient of variation; Prev. = prevalence

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Table 3 - The effect of altitude and agronomic practices on the mean intensity of FHB during 2017 on soft wheat fields in SWE.

Agronomic practices	Class	Proportion of fields (%)	DI[a] (%)	FS[b] (%)	IHS[c] (%)
Previous crop	Barley	5.8	5.9^{cd}	2.1^{d}	7.6^{e}
	Faba bean	5.8	11.0^{cd}	6.2^{cd}	12.3^{de}
	Finger millet	7.7	53.2^{a}	40.2^{a}	48.7^{a}
	Field pea	3.9	12.6^{cd}	9.2^{cd}	16.7^{cde}
	Maize	19.2	36.9^{ab}	26.9^{ab}	34.3^{abc}
	Potato	3.9	24.0^{bc}	5.1^{cd}	11.9^{de}
	Sorghum	5.8	0.0^{d}	0.0^{d}	0.0^{e}
	Soybean	3.9	14.3^{bcd}	12.8^{bcd}	42.7^{ab}
	Tef	28.9	28.9^{bc}	19.4^{bc}	28.0^{bcd}
	Wheat	15.4	36.2^{ab}	36.8^{a}	44.6^{ab}
	LSD		**23.9**	**16.4**	**18.8**
Tillage frequency before of sowing	2 times	9.6	5.0^{c}	4.1^{b}	14.0^{b}
	3 times	26.9	22.4^{b}	18.5^{a}	29.8^{a}
	4 times	28.9	31.0^{ab}	21.2^{a}	26.2^{a}
	5 times	34.6	36.2^{a}	21.6^{a}	26.2^{a}
	LSD		**9.4**	**6.4**	**7.4**
Sowing pattern	Row	73.1	28.5	21.2^{a}	31.4^{a}
	Broadcast	26.9	22.8	12.1^{b}	19.6^{b}
	LSD		**NS**	**8.4**	**9.1**
Wheat varieties	Danda'a	50.0	30.5^{ab}	21.7^{b}	30.6^{a}
	Digalu	25.0	32.3^{ab}	21.8^{b}	28.9^{a}
	Kakaba	6.3	15.2^{c}	18.0^{bc}	36.2^{a}
	Kubsa	6.3	43.1^{a}	32.7^{a}	39.0^{a}
	Triticale	12.5	14.2^{c}	4.3^{c}	9.3^{b}
	LSD		**13.0**	**8.9**	**10.5**

Agronomic practices	Class	Proportion of fields (%)	DI (%)	FS (%)	IHS (%)
Altitude ranges of assessed fields	1711–2269	73.1	29.6	22.8^{a}	32.2^{a}
	2328–2613	26.9	25.5	11.8^{b}	17.6^{b}
	LSD		**NS**	**8.9**	**9.7**
Planting date	July	48.1	31.0	17.7	24.6
	August	51.9	22.9	19.5	29.2
	LSD		**NS**	**NS**	**NS**
Weed infestation [j]	Low	57.7	24.3	19.0	28.5^{a}
	Medium	30.8	34.1	21.2	27.9^{ab}
	High	11.5	19.7	9.9	16.4^{b}
	LSD		**NS**	**NS**	**11.6**
Source of Seed	AGP-II [d]	13.5	47.7^{a}	36.4^{a}	40.8^{a}
	AgrOff [e]	36.5	25.4^{bc}	20.7^{b}	31.1^{ab}
	AsARC [f]	13.5	2.8^{d}	2.7^{d}	14.9^{cd}
	Cascape-JU [g]	9.6	40.9^{ab}	27.9^{ab}	33.1^{ab}
	Farm saved	13.5	14.2^{cd}	4.3^{cd}	9.3^{d}
	LC [h]	13.5	36.2^{ab}	18.9^{bc}	25.1^{bc}
	LSD		**20.2**	**14.7**	**14.7**
Fertilizer application (Kg ha^{-1})	Unfertilized	34.6	22.0	16.1	26.1
	25–50	25.0	32.6	19.1	25.0
	100	40.4	27.3	20.5	28.8
	LSD		**NS**	**NS**	**NS**

Mean values with the same letter within a column did not significantly differ at $P < 0.05$; [a] DI is disease incidence; [b] FS is field severity; [c] IHS is infected head severity; [d] The second agricultural growth program of Ethiopia; [e] Agricultural offices of the respective districts; [f] Assosa agricultural research Centre; [g] Cascape projected implemented by Jimma University; [h] local cooperative in Dedo district; [i] areas with 1500–2300 is cool sub-humid (*Woina-dega*) and 2300–3200 cool and humid (*Dega*) (MoA, 1998); [j] Weed infestation was recorded as low (for low weed infestation); medium (moderate weed infestation) and high (no weeded fields).

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wheat and maize are the main hosts for *Fusarium* spp. that cause FHB in wheat (Kuhnem et al., 2015). Also, *Fusarium* spp. such as *Fusarium graminearum*, *F. culmorum*, *F. verticillioides*, *F. sporotrichoides*, *F. oxysporum,* and *F. solani* were reported as seed-borne pathogens of finger millet in India, that confirmed finger millet as a host for FHB pathogens (Penugonda et al., 2010; Sobha-Rani and Dorcas, 2016). Besides, the soil-borne *Fusarium* spp. (*F. poae,* and other 21 *Fusarium* spp.) were also pathogenic on finger millet seedlings in Nigeria (Akanmu et al., 2013). The pathogenic *Fusarium* species responsible for FHB on wheat across the study area can survive saprophytically on finger millet residues, possibly explaining the higher FHB infection been recorded on wheat fields previously planted by finger millet in the study area.

Maize (corn) as preceding crop, cereal after cereal cropping, and zero or minimal soil tillage were reported to favor the spread of *Fusarium* infection on cereals (Fernandez et al., 2008; Wegulo et al., 2015). A greater FHB severity had been reported in wheat fields directly sown on corn residues when compared to those planted on soybean residue (Dill-Macky and Jones, 2000). These can explain that preceding crops play a great role in promoting FHB severity on the succeeding wheat crop either by being a suitable host which increasing the inoculum levels within the field or by producing bulky crop debris suitable for the saprophytic survival (Dill-Macky and Jones, 2000; Beyer et al., 2007).

According to a study conducted in Uruguay, higher colonization of *Fusarium* species had been observed on residues of wheat and barley than maize, but maize residues can be a source of primary inoculum for three years (Pereyra and Dill-Macky, 2008). Remarkably, all the *Fusarium* species that cause FHB disease are capable of surviving as saprophytes (Parry et al., 1995) on a range of crop residues including corn, small grain cereals, and numerous other grass species and become a primary source of inoculum for FHB disease of wheat (Keller et al., 2003; Dill-Macky, 2008; Pereyra and Dill-Macky, 2008).

A study on the effect of crop rotation on FHB development reported a higher FHB incidence (23.8%) in soft winter wheat planted following corn-soybean rotation, as compared to the lower incidence (0.9–6.0%) in soft winter wheat planted after corn-pea rotation (Del Ponte et al., 2003). This indicate that *F. graminearum* (the dominant FHB pathogen in SWE) can survive on stubbles of field pea that would likely become a potential inoculum source reservoir for the succeeding soft wheat crops (Chongo et al., 2001). Indeed, soft wheat fields previously grown by field pea were showed considerable severity of FHB in SWE.

Besides, viable spores originated from windblown infected residues of wheat or other hosts from one cereal field to the next (Phalip et al., 2006), transportation of infected crop residues and seeds to new areas (Government of Alberta, 2018), and windblown viable aerial ascospores at lower atmosphere up to 182.88 m above ground from distant (over kilometers) that can settle through precipitation or gravitation (Maldonado-Ramirez et al., 2005) may act as a primary source of inoculum for wheat infection (Keller et al., 2014). As a result, wheat plants in fields without cereal residue may also develop FHB disease.

This study found that wheat variety Kubsa was highly infected by FHB having a mean incidence, infected head severity, field severity, and FHB index of 43.1%, 39.0%, 32.7%, and 14.0%, respectively. After that, variety Kakaba had shown higher infected head severity of 36.2%, but it had a moderate field severity of 18.0% (Table 3). Digalu and Danda'a varieties had FHB infections of 32.3% and 30.5% incidence, 21.8% and 21.7% field severities, 28.9% and 30.6% infected head severities, and 10.5% and 8.8% FHB index, respectively (Table 3). Similarly, higher severity of 40.1% had previously been reported on Danda'a variety in the South Omo zone, Southern Nation Nationalities and People (SNNP), Ethiopia (Mitiku and Eshete, 2016).

This investigation found that all the released bread wheat varieties grown in SWE have sustained FHB index ranged from 5.0% to 14.0% (Table 3), while the highest and statistically similar FHB index of 14.0%, 10.49%, and 8.8% was recorded for Kubsa, Digalu, and Danda'a varieties, respectively (Table 3). Similarly, Abdissa and Bekele (2020) reported that all the improved varieties under production (including Kingbird, Danda'a, Kakaba, Kubsa, and Digalu) were susceptible to FHB. These results indicate that the two most popularly grown wheat varieties (Danda'a and Digalu) were

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susceptible to FHB disease of wheat like Kubsa variety, suggesting that FHB could pose a major threat to wheat production across SWE in case an epidemic of FHB could occur. Therefore, it is of great importance the screening for FHB resistant wheat varieties across all available wheat genotypes for Ethiopia to reduce the risk of the disease development in the country.

In contrast, lower mean incidence (14.2%), field severity (4.3%), infected head severity (9.3%), and FHB index (0.8%) had been recorded on *Triticale* cultivar across SWE (Table 3). *Triticale* cultivars found across SWE can grow more than 150 cm tall. According to the study conducted during 2013 and 2014 in Ottawa (Ontario, Canada), taller eastern spring wheat varieties showed a strong negative relationship with the FHB index, meaning that the spikes of the taller plants were less prone to FHB infection. Furthermore, the microclimate of taller plants is less favorable to FHB disease due to lower relative humidity (Moidu et al., 2015), thus explaining why also in SWE *Triticale* is less vulnerable to FHB infection. Additional investigation is needed to confirm whether plant height or other traits can explain the lower FHB infection on *Triticale*.

In SWE, higher FHB incidences and severities were recorded from wheat fields tilled 3 to 5 times by the traditional ox traction system ahead of wheat seeding (Table 3). The traditional land tillage practiced in Ethiopia does not bury all the left-over crop residues into the soil. Also, farmers usually left crop residues in the field as it is, or collect them together in small humps within the field. Those left-over remnants may serve for the saprophytic survival of FHB pathogens, which could be a source of primary inoculum for the following cropping season. Even the more intensive tractor plowing did not decrease FHB incidence as compared to conventional tillage, reasonably due to the returning effect of buried crop residues onto the soil surface (Lenc, 2015). To overcome this, inverted tillage (moldboard) for land preparation had recommended to buried the *Fusarium*-infected crop residues deep into the soil in developed countries (Dill-Macky and Jones, 2000; Pereyra et al., 2004; Lenc, 2015; Hofgaard et al., 2016).

Relationship of FHB incidence and severity with independent variables

Analysis of multivariate linear regression revealed that 28.3% variability in incidence and 31.3% variability in field severity had been explained by nine explanatory variables (Table 4).

Table 4 - Multiple regressions for wheat scab incidence and severity on independent variables in SWE, 2017 main cropping season.

Independent variables	FHB incidence			FHB field severity		
	Coefficients	**Type-III SS**	**P-values**	**Coefficients**	**Type-III SS**	***P*-value**
Intercept	-13.26	-	-	-23.46	-	-
Altitude (m)	11.90	448.14	0.317	14.86	698.17	0.042
Wheat variety	0.49	6.87	0.901	-1.24	44.69	0.657
Source of seed	-1.78	99.59	0.635	-0.25	1.98	0.925
Frequency of tillage	9.30	2878.02	0.014	6.13	1248.37	0.023
Sowing date	-2.28	42.07	0.758	4.65	175.24	0.381
Sowing pattern	-4.51	104.97	0.626	-2.23	25.68	0.736
Previous crop	2.14	364.40	0.366	0.63	31.53	0.709
Weed infestation	-6.69	750.18	0.197	-6.62	735.28	0.077
Fertilizer application	0.06	304.08	0.409	0.03	88.50	0.533
R^2		**28.3%**			**31.3%**	
Adj. R^2		**11.8%**			**15.4%**	
Pr> F		**0.118**			**0.069**	
Intercept	-5.60			-4.08		
Rainfall [a]	0.044	3619.35	0.006	0.03	1773.28	0.008
R^2		**15.3%**			**14.0%**	
Adj. R^2		**13.4%**			**12.2%**	

[a]The total rainfall from August to November 2017 during the period when wheat was flowering to hard dough stages; SS = sum of squares

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The information brought by most of the explanatory variables was not significant for both incidence and field severity (Table 4). However, the frequency of tillage ahead of seeding wheat brings significant information to explain the variability in FHB incidence and field severity. Similarly, differences in altitude can explain the variability in field severity across SWE. Furthermore, 15.3% of the variability in incidence and 14.0% of the variability in field severity were significantly correlated with (at $P < 0.05$) the total rainfall that occurred from wheat flowering to hard dough stages (Table 4). Therefore, the frequency of tillage ahead of seeding wheat, altitude, and the total rainfall that occurred during flowering to hard-dough stages were the most influential variable in explaining the variability of FHB in SWE (Table 4).

The risk of FHB disease is correlated with the prevailing weather conditions such as warm and humid conditions, during flowering (Xu, 2003; Popovski and Celar, 2013). The frequent rainfall, high humidity, and heavy dew during flowering to soft-dough stages favour FHB infection in wheat (Osborne and Stein, 2007; Popovski and Celar, 2013; Nazari et al., 2018; Schöneberg et al., 2018). In SWE, the temperature during the flowering to soft dough stages of wheat growth (from August to November 2017), ranged from 11.8 to 25.9 °C, and the precipitation ranged from 40.68 to 323.58 mm. These conditions were favourable for the infection of wheat spikes.

Conclusions

Fusarium head blight of wheat is becoming an important fungal disease of improved soft wheat varieties across SWE as compared to the *Triticale* variety, particularly in the Buno-Bedele zone of the Oromia region. In SWE, the incidence and field severity of FHB on wheat was mostly influenced by the tillage frequency ahead of seeding wheat, altitude, and the total rainfall that occurred during flowering to the hard dough stages. Therefore, the management of FHB of wheat across SWE should be focused on the use of *Fusarium* free wheat seed, fungicide efficacy evaluation, and screening of bread wheat genotypes for FHB resistance. Also, the evaluation of the incidence of the several *Fusarium* species associated to FHB and the levels of their mycotoxins should be carefully monitored.

Declaration of interest

The authors have not declared any conflict of interest.

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