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Yield Loss Associated with Soya Bean Rust (*Phakopsora pachyrhizi* Syd.) in Uganda

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Abstract

Studies were conducted to quantify the yield loss attributable to soya bean rust, a relatively new disease in Uganda. This was carried out for three consecutive seasons in the central, eastern, northern and western parts of the country, using three commercial varieties (Nam 1, Nam 2 and Namsoy 3) and two elite varieties (UG-5 and GC-00138-29). The commercial varieties recorded higher yield losses (26.9–36.3%) and higher rust severities > 50%, whereas the elite varieties recorded lesser yield losses of < 10% and rust severities of < 30%. Yield losses were highest in the central region (22.9%), and lowest in the northern region (15.1%). Yield losses differed significantly between seasons and were associated with reduction in seed weight and filled pod per plant.

Introduction

Soya bean rust (*Phakopsora pachyrhizi* Syd.) has, for a long time, been restricted and or confined to the tropical and sub-tropical countries in Asia, the Americas and on the Australian continent, where it causes significant yield losses (Bromfield, 1984). Not until the late 1970s in Zambia (Javid and Ashraf, 1978) and the early 1980s in Togo (Mawuena, 1982), were the first reports on soya bean rust documented on the African continent. Thereafter, the disease has been reported in many sub-Saharan African countries. In Uganda, however, the disease was first observed on experimental plots at Namulonge Agricultural and Animal Production Research Institute (NAARI) in 1996, and thereafter the disease was observed on farmers' fields throughout the country (Uganda Seed Project, 2000), with all the commercial cultivars Nam 1, Nam 2 and Namsoy 3 heavily succumbing to the disease. Rust is conspicuous on leaves, although lesions also appear on petioles, pods and stems (Bromfield, 1984; Hartman et al., 1999). The most commonly observed symptom is that of sporulating lesions on the lower surface of the leaf (Tschanz and Shanmugasundaram, 1985; Hartman et al., 1999).

It has been observed that higher lesion density is associated with premature yellowing and defoliation (Bromfield, 1984). Rust lowers soya bean yields through premature defoliation by decreasing the number of normal pods per plant, weight of seeds per plant, and the 100-seed weight (Bromfield, 1984). The extent of yield loss depends on the crop growth stage at which the disease starts and its intensity (Ogle et al., 1979; Hartman et al., 1991).

In areas where the disease is endemic, yield losses as high as 80% have been reported on susceptible cultivars (Bromfield, 1984; AVRDC, 1992). Whether the disease causes economic loss or not in the different soya bean agro-ecologies of Uganda is not known. However, before developing and/or implementing any control strategies against a relatively new disease in a country, it is necessary to quantify the extent and nature of damage attributable to that disease, in this case soya bean rust. Thus, the objective of this study was to determine the extent of yield loss caused by soya bean rust and determine the effect of location on such losses.

Materials and Methods

The study was conducted at four sites: Namulonge Agricultural Research Institute (central region), Nakabango Experimental Station (eastern region), Masindi Seed Project Farm (western region) and Ngetta District Farm Institute (northern region). The experiment was run for three consecutive seasons: October 2000–January 2001, March 2001–June 2001 and October 2001–January 2002. Hereafter, these seasons will be referred to as 2000B, 2001A and 2001B, respectively. The test genotypes used in the study are listed in Table 1. Each variety was subjected to two fungicide sprays consisting of Saprol (triforine, systemic) and Dithane M-45 (protectant) at rates of

Table 1
Soya bean genotypes used in the study

Genotype	Origin	Pedigree	Remarks
UG-5	Uganda	Unknown	Experimental
GC-00138-29	AVRDC*	(CH#1 × Anoka) × (Clarke 63 × 64.4)	Experimental
tx4500Nam 1	Colombia	Hales X P1307-861	Commercial
Nam 2	Nigeria	87D-668	Commercial
Namsoy 3	Uganda	TGx 1019-2E X Nam 1	Commercial

*Asian Vegetable Research and Development Centre in Taiwan.

2 ml/l and 2.5 g/l, respectively. These fungicides were applied separately.

The experiment was arranged in a split-plot design with three replicates. The main plots were those with and without the fungicide applications, while the sub-plots were the varieties. Each experiment unit consisted of four rows measuring 2 m. There were 2 m alleys between the plots and replicates to avoid inter-plot interference. Two rows of Nam 2, which is highly susceptible to rust, was sown between replicates to act as a guard row around the experimental area to provide maximum inoculum pressure. For the fungicide-treated plots, spraying commenced at early bloom (R1) at a weekly interval up to full seed formation (R6). Crop growth stages were defined following Fehr and Caviness (1977).

In total six sprays were applied on each variety. The experiment was kept weed-free by regular hand-hoeing. At R6 growth stage, rust assessment was performed on all the cultivars in the unprotected plots, so as to quantify the rust-susceptibility of individual cultivars in the different agro-ecologies. This was performed on five randomly selected plants in the two middle rows. For each plant, the plant canopy was divided into three positions (top, middle and bottom), with approximately the same number of nodes. The under surface of sampled leaf at each of these plant canopy positions was assessed for rust (percentage of leaf surface occupied by rust lesions). This was performed because rust severity varies across the plant canopy position (Kitani, 1952; Omar and Ismail, 1982). The percentage severity scale of 0–9, where 0 = no disease and 9 = 90% disease plus defoliation was adopted (Walla, 1979 cited by Sinclair, 1982). The mean of the top, middle and bottom leaf severities was then computed.

All the plants in the two middle rows were harvested, sun-dried and then threshed. Moisture content was determined from a 100 g sample per plot using a steinlite moisture tester (Steinlite Model 400-G tester, Stein Laboratories Inc., Kansas). Yield loss was determined using the formula:

$$\%\text{Yield loss} = \frac{\text{yield of sprayed plots} - \text{yield of unsprayed plots}}{\text{yield of sprayed plots}} \times 100$$

Rust tolerance index (RTI) was computed as follows:

$$\text{RTI} = \frac{\text{yield of unprotected plots}}{\text{yield of rust-protected plots}}$$

In addition, five plants per plot were selected randomly from the remaining two rows. These were used to count the total number of pods per plot and the number of filled pods, that resulted in the computation of percentage filled pods. Weight of 100-seeds was also determined for each plot.

Data were subjected to analysis of variance using Genstat Computer Package 3.2 (Lawes Agricultural Trust, 1995). Preliminary analysis indicated that Saprol was more effective than Dithane-M45 in controlling soya bean rust and was therefore adopted in computation of yield loss and RTI. Yield loss data and RTI across locations and seasons were pooled to determine genotype × environment interactions. Mean values were separated using standard error of difference (SED) and the two means values were declared significantly different when the difference between them was greater than twice the SED.

Results

Rust severities on soya bean varieties at full seed formation

Results of rust severities are presented in Table 2. Results consistently indicated significant differences in percentage rust severities between the soya bean varieties, with severities being significantly higher ($P < 0.001$) during 2001A. Soya bean varieties UG-5 and GC-00138-29 consistently had low rust severities (<25%), while soya bean varieties Nam 1, Nam 2 and Namsoy 3 consistently had higher severities as high as 60% (Table 2). Results indicated that Namulonge had the highest rust severity, followed by Nakabango, Masindi and Lira.

Determination of yield loss

Results for yield of rust-protected and rust-unprotected soya bean varieties are presented in Table 3. Rust-protected plots of soya bean varieties Nam 1, Nam 2 and Namsoy 3 yielded significantly higher than their rust-unprotected control plots (Table 3). It was, however surprising that unprotected UG-5 at Namulonge, Masindi and Lira yielded higher than the protected UG-5. Similarly, unprotected GC-00138-29 at Nakabango yielded higher than the protected GC-00138-29 (Table 3). Results further indicated that within the rust-protected plots, varieties Nam 1, Nam 2 and Namsoy 3 yielded more or slightly less than varieties UG-5 and GC-00138-29 (Table 3). Within the unprotected plots (controls), significant differences in yield were obtained between the soya bean varieties, with varieties GC-00138-29 and UG-5 yielding higher than varieties Nam 1, Nam 2 and Namsoy 3.

Table 2
Percentage mean severities of rust on five soya bean varieties at four locations in Uganda[1]

	Namulonge			Nakabango			Masindi			Lira[2]	
Variety	2000B[3]	2001A	2001B	2000B	2001A	2001B	2000B	2001A	2001B	2001A	2001B
UG-5	5.8	27.5	21.3	15.3	16.4	21.5	0.9	11.2	4.4	1.3	12.6
GC-00138-29	4.2	24.4	22.6	12.0	16.9	10.6	0.9	18.9	1.9	4.4	13.7
Nam 1	71.1	71.3	71.3	66.8	71.6	66.8	40.9	64.5	43.3	15.5	43.3
Nam 2	66.5	72.3	75.1	72.9	62.8	50.5	42.0	69.4	35.5	14.2	62.2
Namsoy 3	68.0	71.3	68.2	65.8	60.2	50.7	32.2	60.9	28.2	16.4	48.5
SED[4]	7.01	8.08	7.9	3.45	5.92	6.5	8.17	5.72	7.8	3.3	5.2
CV (%)[5]	19.9	18.5	25.6	9.0	13.8	15.6	34.5	17.8	21.8	38.9	25.7

[1]Averaged rust severities (0–9 scale Walla, 1979) across three canopy positions (top, middle and bottom) at full seed formation;
[2]Data for Lira (2000b) was not collected due to damage caused by goats on the trial;
[3]A and B correspond to the first (March–June) and second (October–January) seasons, respectively;
[4]Separates mean values between varieties;
[5]Coefficient of variation.

Table 3
Comparison of yield (kg/ha) and yield loss (%) of five soyabean varieties grown under protected and rust-unprotected conditions at four locations in Uganda[1]

	Namulonge			Nakabango			Masindi			Lira		
Variety	Rust protected	Control	% Yield loss	Rust protected	Control	% Yield loss	Rust protected	Control	% Yield loss	Rust protected	Control	% yield loss
UG-5	1305	1543	−18.2	1742	1552	10.9	607	622	−2.4	995	1130	−13.5
GC-00138-29	1370	1064	22.3	1510	1536	−1.7	671	563	16.0	1027	889	13.4
Nam 1	1410	972	31.0	1560	1127	27.7	1005	804	20.0	1498	1009	32.6
Nam 2	1662	958	42.3	1736	948	45.3	862	598	30.0	1618	1311	18.9
Namsoy 3	1678	953	43.2	1875	1255	33.1	1075	732	31.9	1341	984	26.6
SED[2]	124.8			165.8			88.1			109.1		
SED[3]	131.6			184.1			98.3			108.9		
CV (%)[4]	12.5			15.1			29.6			11.3		

[1]Mean across three (2000B, 2001A and 2001B) and two seasons for Lira (2001A and 2001B);
[2]Separates mean between treatments values i.e. between control and protected plots;
[3]Separates mean within treatments i.e. within control or within protected plots;
[4]Coefficient of variation.

It was also observed that at each location the extent of yield loss varied markedly between the varieties (Table 3). At Namulonge, highest (43.2%) and lowest (22.3%) yield loss were recorded on varieties Namsoy 3 and GC-00138-29, respectively, while highest (45.3%) and lowest (10.9%), loss were recorded on Nam 2 and UG-5 at Nakabango. For Masindi, highest (31.9%) and lowest (16.0%) losses were recorded, respectively, on Namsoy 3 and GC-00138-29, and at Lira, highest (32.6%), and lowest (13.4%) losses were, respectively, recorded on Nam 1 and GC-00138-29 (Table 3).

Pooled analysis showed significant differences in yield loss and RTI between the soya bean varieties (Table 4). Nam 2 had the highest yield loss (36.3%), while GC-00138-29 had the lowest (1.9%). On the other hand, UG-5 had the highest RTI (1.02), while Nam 2 had the lowest (0.66).

Although results did not indicate significant differences in yield loss and RTI between the locations, soya beans at Namulonge showed highest yield loss (22.9%) and lowest RTI (0.77), while at Lira the crop had the lowest yield loss (15.1%) and highest RTI (0.85) (Table 5).

Table 4
Mean yield loss (%) and RTI of five soya bean varieties across four locations and three seasons

Variety	% Loss	Rust tolerance index
UG-5	−2.4	1.02
GC-00138-29	1.9	0.98
Nam 1	26.9	0.73
Nam 2	36.3	0.64
Namsoy 3	33.2	0.66
SED	5.8	0.06
CV (%)	10.2	36.7

Table 5
Mean yield loss (%) and RTI of five soya bean varieties across three seasons

Location	% Loss	Rust tolerance index
Namulonge	22.9	0.77
Nakabango	22.4	0.78
Masindi	16.2	0.83
Lira	15.1	0.85
SED	5.2	0.05
CV (%)	39.9	89.4

Table 6
Comparison of filled pod (%) and 100-seed weight (g) between rust-protected and unprotected soyabean varieties at four locations in Uganda[1]

	Namulonge				Nakabango				Masindi				Lira			
	Filled pods		Seed weight		Filled pods		Seed weight		Filled pods		Seed weight		Filled pods		Seed weight	
Variety	Clt.	Prt.	Clt.	Prt.	Clt.	Prt.	Clt.	Prt.	Clt.	Prt.	Clt.	Prt.	Clt.	Prt.	Clt.	Prt.
UG-5	87.2	89.1	14.9	15.0	83.4	80.4	17.0	17.5	83.9	88.7	15.1	15.6	95.2	95.7	16.1	16.3
GC-00138-29	81.1	83.4	15.0	15.1	82.7	88.2	15.5	17.3	79.6	86.5	13.9	14.1	86.0	88.0	15.3	14.4
Nam 1	70.0	85.8	8.9	11.1	72.4	80.5	9.5	11.9	79.1	83.2	9.7	10.6	89.1	90.1	9.3	10.0
Nam 2	69.9	89.6	9.6	13.9	69.7	86.4	11.7	15.2	86.0	84.1	12.6	13.9	93.0	94.7	12.5	14.5
Namsoy 3	77.4	89.6	11.8	14.3	86.4	87.5	11.9	15.4	74.5	81.2	11.7	13.7	87.5	90.8	12.2	14.0
SED[2]	3.02		0.53		5.58		0.51		6.42		0.82		2.79		0.39	
SED[3]	3.07		0.40		6.15		0.56		6.46		0.56		3.07		0.38	
CV (%)[4]	4.6		3.8		9.3		4.8		9.6		8.8		4.1		3.4	

[1]Pooled data for three seasons (2000B, 2001A and 2001B), except for Lira with only two seasons (2001A & 2001B. Clt. = unprotected plots; Prt. = rust-protected plots;
[2]Separates mean between treatments, i.e. between control and protected plots;
[3]Separates mean under the same treatment, i.e. within control or within protected values;
[4]Coefficient of variation plots.

Effect of rust on yield components

Results of rust-protected and unprotected yield components (filled pods and 100-seed weight) are presented in Table 6. It was only at Namulonge and Nakabango rust-protected plots of varieties Nam 1, Nam 2 and Namsoy 3, showed significantly higher filled pods than the unprotected plots. Within the rust-protected plots at all the locations, there were no significant differences in filled pods between the soya bean varieties (Table 6). In fact, all varieties had $>80\%$ pods filled. Within the unprotected plots, however, significant differences in filled pods were obtained at Namulonge and Nakabango. Nevertheless, it was Nam 1, Nam 2 and Namsoy 3 that had fewer filled pods than UG-5 and GC-00138-29 (Table 6).

At Namulonge and Nakabango, rust-protected plots of soya bean varieties Nam 1, Nam 2 and Namsoy 3 had significantly higher seed weight than the unprotected plots (Table 6). However, at Masindi and Lira, soya beans of rust-protected plots of varieties Nam 2 and Namsoy 3, respectively, had significantly higher ($P < 0.001$) seed weight than the unprotected plots. It was observed that at all the locations rust-protected plots had higher seed weight than their unprotected counterparts.

Discussion

Although there were reports of a severe outbreak of soya bean rust in Uganda, no quantification and/or verification of the disease had since then been carried out. Hence studies were conducted to establish the presence and damage levels of the disease in the central, eastern, western and northern regions of the country. Indeed, the epidemic is underway in these regions, but the damage levels vary markedly between soya bean varieties and locations. Varieties UG-5 and GC-00138-29 were quite resistant, with lower rust severities, lower yield losses and clearly higher RTI. In marked contrast, varieties Nam 1, Nam 2 and Namsoy 3 were highly susceptible with higher disease severities, higher yield losses, and lower RTI.

In related studies conducted at the Asian Vegetable Research Development Centre in Taiwan (AVRDC, 1988), significant yield losses were recorded when 30% of leaf area was affected at the R6 growth stage, while negligible losses occurred when $<20\%$ of the leaf area was affected at the R6 growth stage.

Results further suggest that rust establishes earlier on susceptible varieties than on relatively resistant varieties. Higher severities on susceptible varieties than on the resistant varieties at same growth stage R6 is evidence to this fact.

This phenomenon could further explain the variation in yield losses between these soya bean varieties. These findings are in agreement with earlier studies by Tschanz and Wang (1980) that susceptible soya bean varieties succumbed to rust earlier (73 days after planting) than the resistant varieties (97 days after planting).

The lower yield obtained from rust-protected plots of UG-5 which is fairly resistant as compared with unprotected plots is probably because of a phototoxic effect of fungicides on resistant soya bean varieties. For the susceptible soya bean varieties (Nam 1, Nam 2 and Namsoy 3), there was a consistent yield increase in all the rust-protected plots. Very comparable results have been reported in China (Chan and Tsaur, 1975) and in Uganda (Tukamuhabwa et al., 2001), where rust-protected plots of resistant varieties gave lower yields as compared with their unprotected counterparts. This observation clearly demonstrates the superiority of host plant resistance.

Differences in yield loss and RTI between locations are most likely due to variation in existing inoculum pressure between locations. It is also plausible that it may be due to different levels of aggressiveness of the pathogen (or virulence) in these locations. However, differences in aggressiveness of the pathogen in these locations are yet to be confirmed. Bromfield et al.

(1980) observed that isolates of *P. pachyrhizi* from different geographical regions differed in virulence on an array of soya bean genotypes. Thus, yield losses associated with rust are undoubtedly supposed to vary from one region to the other. The obtained results suggest that the aggressiveness (or disease pressure) of the pathogen is highest in the central, followed by eastern, western and northern regions of Uganda.

Variations in disease onset dates could also partly account for the differences in yield loss and RTI between the locations. Based on the results, disease onset appears to be earlier at Namulonge and Nakabango than at Masindi and Lira. Differences in rust severities at the same crop growth stage between locations is evidence to this fact. Consequently, Namulonge and Nakabango showed higher yield losses and lower RTI as compared with Masindi and Lira. Comparable results were observed in Taiwan (Tschanz and Wang, 1980), where at one location (Hualien) all the varieties planted reached 10% severity, 25 days earlier than their counterparts at other locations.

Regions with well distributed rainfall patterns, moderate temperatures, 18–26°C (Tschanz, 1982), coupled with extended conditions of leaf wetness (Casey, 1979), are reported to favour severe rust epidemics. On the other hand, extreme temperatures (>30 or <15°C), and or dry conditions retard rust epidemics. The selected regions differed markedly in these climatic aspects. These climatic variations could also explain the variation in yield loss and RTI between the locations. For example, during the growing seasons, the daily mean values of minimum, maximum temperatures, and rainfall amounts were 15.5°C, 27.6°C, and 4.7 mm, respectively at Namulonge, while it was 12.9°C, 30°C, and 4.2 mm, respectively at Lira. The prevailing conditions at Namulonge were therefore more favourable for the rust epidemic than in Lira, and thus higher yield losses occurred at Namulonge. Clearly, variation in inoculum pressure, differences in disease onset, and climatic differences (temperature and rainfall), either in combination or independently, are responsible for the yield loss differences between the locations.

Seasonal variations in yield losses and RTI at the same location are most likely due to differences in prevailing climatic conditions between seasons. For instance, during 2001A, daily mean of minimum temperatures ranged between 13.5 and 17.9°C; maximum temperatures between 27.8 and 29.9°C, and rainfall between 2.7 and 4.9 mm. However, during 2000B, minimum temperatures ranged between 13.4 and 16.7°C, maximum temperatures between 27.6 and 29.9°C, and rainfall between 4.1 and 5.0 mm. Thus, any variation in climatic conditions can considerably determine the rust epidemic. Studies conducted in Thailand (Sangawongse et al., 1977), showed that yield losses of 10–15% were recorded in the dry season, as compared with 100% losses recorded during the rainy season.

Yield loss was associated with a reduction in 100-seed weight, number of filled pods per plant and early maturity for the susceptible varieties. Studies conducted elsewhere (Ogle et al., 1979; Bromfield, 1984; Hartman et al., 1991; Sache and Zadoks, 1994) have also indicated that yield loss attributable to rust is associated with a reduction in number of pods per plant and seed weight. Significant variety $\times$ location interaction for yield loss and RTI is indicative of the differential response and/or performance of varieties across locations. For instance, Namsoy 3 had the highest yield loss at both Namulonge and Masindi, while Nam 2 and Nam 1 had the highest yield loss at Nakabango and Lira, respectively. Thus, selection is needed before deployment of varieties across agro-ecological zones. The high yield losses require that new and more rust-tolerant varieties should be identified. The two elite varieties, UG-5 and GC-00138-29, appear plausible candidates.

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