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DETERMINATION OF FIELD YIELD LOSS AND EFFECT OF ENVIRONMENT ON POD SHATTERING IN SOYBEAN

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ABSTRACT

Pod shattering in soybean is a major production constraint causing high field yield losses in the tropic and sub tropics. With regard to pod shattering, soybean varieties can be categorised as tolerant, intermediate or susceptible. Six soybean lines, Nam 2, TGx 1448-2E, Duiker, Nam 1, TGm 737P and Kabanyolo 1 were grown at three locations for three seasons (1997 - 1998) to determine field seed yield losses due to pod shattering and the effect of G X E interactions on shattering. Based on the number of shattered and unshattered pods, the amount of soybean seed yield lost in the field due to pod shattering was determined. Yield losses in susceptible and intermediate susceptible varieties ranged from 57 - 175 kg ha $^{-1}$ and 0 - 186 kg ha $^{-1}$, respectively depending on genotype, location, season and harvesting date. The resistant varieties did not shatter even when harvested after a delayed harvesting period of 21 days. Field yield loss due to pod shattering was estimated and such estimates are considered useful for breeding programmes when selecting varieties for resistance to shattering.

Key Words: Genotype x environment interactions, *Glycine max*, susceptible varieties

RÉSUMÉ

L'éclatement de gousses de soja et la contrainte majeure à la production causant des pertes dans les tropiques et les sub-tropiques. Concernant l'éclatement de gousses, les variétés de soja peuvent être classées comme tolérantes, intermédiares ou susceptibles. Six lignées de soja, Nam2, TGx 1448-2E, Duiker, Nam1, TGm 737 P et Kabanyolo 1 étaient plantées en trois endroits et pour trois saisons (1997-1998) pour déterminer les pertes en graines dans les champs causées par l'éclatement de gousses et les effets de l'intéraction GxE sur l'éclatement. Se basant sur le nombre de gousses éclatées et non-éclatées, la quantité de soja perdue dans les champs par éclatement était déterminée. Les pertes de rendements pour les variétés susceptibles et intermédiaires rangées entre 57 et 175 kg ha $^{-1}$ et 0 et 186 kg ha $^{-1}$, respectivement ; selon le génotype, la location, la saison et la date de la moisson. Les variétés résistantes n'ont pas éclaté même quand elles étaient récoltées avec 21 jours de retard. La perte en champs due à l'éclatement de gousses était estimée et ces estimations sont considérées très utiles dans les programmes de transformations quand les variétés résistantes à l'éclatement sont sélectionnées.

Mots Clés: Intéraction génotype et environnement, *Glycine max*, variétés susceptibles

INTRODUCTION

The cultivated soybean *Glycine max* (L) Merr. (2n = 40) is a relative of wild soybean *Glycine soja* (2n = 40) and was first domesticated in China some 3000 years ago (Hapgood and Johns, 1987). The major areas of soybean production were restricted to temperate regions until the mid-

1940's, when the area of production started to expand to tropical and sub-tropical regions. The new production areas are characterised by warmer and more humid conditions, which pose different production problems such as pod shattering and reduced seed viability (Franca Neto and Henning, 1994), pests and diseases.

Seed losses of 34-99% are often associated with pod shattering in susceptible varieties and delayed harvesting after maturity (Tiwari and Bhatnagar, 1991). Shortage of labour and harvesting equipment can delay harvesting, leading to seed yield loss. To overcome this, there is need to develop varieties that are resistant to shattering, that can stand relatively longer periods in the field after dry maturity without shattering.

In field trials, Philbrook and Oplinger (1989) observed shattering as prime source of field losses in soybean in the South Eastern USA, contributing 37% of total losses, but was overcome by early harvesting. They estimated yield losses due to shattering at 53 - 310 kg ha^{-1}, and showed that harvesting delays of 0 to 14 and 28 to 42 days after soybean maturity were not significant. Significant year x cultivar x harvest delay ($P < 0.05$) and cultivar x harvest delay interactions ($P < 0.05$) were observed. A survey conducted in Benue state, Nigeria, revealed that resistance to pod shattering was a pre-requisite for adoption of any variety by the farming communities (Sanginga *et al.*, 1999).

Tsuchiya (1987) reported low humidity, high temperature, rapid temperature changes, and alternating wetting and drying of soybean plants as common factors that induced pod shattering. Tiwari and Bhatnagar (1989) also reported that pod shattering was enhanced when rains were followed by dry weather at harvesting. Jiang *et al.* (1991) evaluated 216 soybean varieties and observed that shattering percentage increased with decreasing pod moisture content.

Akpan (1988) observed G x E interactions for shattering over seasons in populations of soybean at two locations in Nigeria. Tiwari and Bhatnagar (1993) tested 9 lines of soybean for shattering stability across five locations in India and found the resistant genotypes (1.85 - 3.24% shattering) stable over the locations, suggesting minimal G x E effects ($P<0.05$) for resistance to pod shattering. However, susceptible lines ranged between 1.27 - 45.53% shattering and showed significant G x E effects ($P < 0.05$), suggesting that susceptibility to shattering was unstable. Similarly, significant G x E interactions ($P < 0.01$) for pod shattering were observed by Bailey *et al.* (1997) using F_4 populations of soybean grown at two locations within season in the USA. These works, however, reflect lack of seed yield losses estimates due to shattering.

This paper presents results of a study conducted with a view to determine yield loss due to soybean pod shattering in the field under different environmental conditions.

MATERIALS AND METHODS

The experiment was planted at three locations; Namulonge (0^0 32N', 32^0 37'E and 1148 m.a.s.l), Nakabango (0^0 29'N, 33' 14'E and 1219 m.a.s.l) and Iki-Iki (1^0 02'N, 33^0 57'E and 1158 m.a.s.l) in Uganda during 1997A, 1997B and 1998A (where, A and B refer to first and second growing seasons, respectively). Three pod shattering resistant varieties, TGx 1448-2E , Nam 2 and Duiker, two interemediate, Nam 1 and Kab 1, and one susceptible variety, TGm 737P were used.

Maturity of the varieties was synchronised by planting in a time-staggered manner (Table 1). The experiment was arranged in a randomised complete block design with three replicates. Plot size was 500 cm x 360 cm with six rows. Spacing between rows was 60 cm and 5 cm within rows. The crop was kept free of weeds by hoe weeding wherever necessary.

At physiological maturity (R8 stage - when 95% of the pods have turned golden yellow) a Stephenson screen containing a portable psycrometer and maximum and minimum thermometer were placed in the trial, one metre above the soil level. Dursban (Chloropyriphos, 5G) was applied along the rows at ground level to prevent plant damage by termites. A tru-check rain gauge model TRU 202 was also positioned in the trial at the same time. Temperature and relative humidity(RH) were recorded at 10.00 am, 12.00 noon and 4.00 pm daily until the harvesting was completed. Rainfall (mm) was also recorded.

Determination of yield losses due to pod shattering. At harvest, the plots were sub-divided into three sub-plots comprising of two rows. Harvesting sub-plots was done randomly at an interval of 7 days after R8 stage until 21 days later. From each subplot of two rows, 90 to 130 plants were harvested and used to determine the number of unshattered and shattered pods on each plant. Data from sub-plots were treated as repeated observations (Little and Hills, 1978). Seed weight and moisture content were determined using seed from the unshattered pods and yield was adjusted to 12% moisture content. On the assumption of equal yield (weight) per pod in each variety, and basing on recorded shattered and unshattered pods in relation to actual seed yield per plot and seed yield lost due to pod shattering were estimated as follows:

$$Y_t = (Y_p/P_{un}) * (P_{un} + P_{sh}) \quad (1)$$

$$Y_{ls} = (Y_p/P_{un}) * P_{sh} \quad (2)$$

Where, Y_t = expected total plot yield

Y_p = actual plot yield

P_{un} = total number of pods unshattered

P_{sh} = total number of pods shattered

Y_{ls} = total yield loss due to shattering

The data were analysed to estimate the effect of G x E interactions on genotypes, using general linear model procedure. Possibilities of associations between soybean pod shattering and temperature, humidity and rainfall were determined using Pearson correlation analysis. Data were subjected to ANOVA using SAS computer software, version 6.12 (Anon,1988). To conform to the assumption of equal of variance, plot yield loss was recorded as percentage of total yield and then subjected to arcsine transformation (Sokal and Rohlf, 1995) prior to analysis. Varieties TGx 1448-2E, Duiker and Nam 2 did not shatter and were, thus, excluded from analysis (Milken and Johnson, 1992). Due to the 'El Nino' weather conditions in which rainy conditions above normal prevailed most of the time during the second rain season of 1997 (1997B), there was no shattering exhibited by the varieties, except TGm 737P. Since the season was characterised by unusual conditions, the results of 1997B were also eliminated from the analysis (Milken and Johnson, 1992).

TABLE 1 . The staggered order of planting and days to maturity of the cultivars used

Genotype	Days after first planting[1]	Days to maturity
TGm 737P	14	75
Kabanyolo 1	7	95
Nam 1	0	110
Duiker	7	93
TGx 1448-2E	0	112
Nam 2	0	112

[1]0 = Varieties designated by 0 days were sown on first day of planting. Those marked by 7 and 14 days were sown 7 days and 14 days after first date of planting, respectively.

Validation of the method used in estimating yield loss. The accuracy of the method used in estimation of seed loss due to pod shattering was validated using 20 plants from the two guard rows per plot that shattered in the field. At harvest, varieties TGm 737P, Kab 1 and Nam 1 grown at Namulonge were harvested before any pod shattering. The harvested plants were placed in paper bags, stapled and oven-dried at 80°C for 5 hours.

Each row harvested represented a plot, making six replications per genotype. Seeds from shattered pods were trapped in the paper bags, weighed directly to form actual yield loss. Actual total yield per plot was determined by adding weights of seed from shattered and unshattered pods. Extrapolation of yield loss and total yield was done using formulae 1 and 2 above. The accuracy of using yield per pod was checked by extrapolation of total yield, estimated using shattered pods and unshattered pods to form actual field yield 1 and actual field yield 2.

The accuracy of estimation of yield loss and total yield, actual yield loss and actual total yield from observed data set 1 and the corresponding extrapolated yield loss and total yield in observed data set 2 were compared using a t- test (Sokal and Rohlf, 1995) to determine the extent to which actual data deviated from extrapolated data.

RESULTS AND DISCUSSION

Verification of accuracy of the model used to determine yield loss due to pod shattering. The results of actual and extrapolated yield and yield loss due to pod shattering are presented in Table 2. Based on t-tests (Sokal and Rohlf,1995), the two methods were not significantly different. Out of the nine comparisons made between the results obtained through estimation and those weighed directly, eight were not significantly different. This observation confirms the extrapolation method used in the study as a dependable tool for estimation of total seed yield and total seed yield loss due to pod pod shattering in the field. The main limitation of the method is the need to have unshattered pods remaining on some plants where pod shattering has taken place. The method, however, can be used when the shattered seed on the ground is not available or has been picked by birds as was the case at Namulonge Agricultural and Animal Research Institute (NAARI). This method is cost effective in that it does not require any special equipment.

Yield loss due to pod shattering and effect of genotype x environment interactions. Mean squares for the ANOVA for seed yield loss among genotypes, locations and seasons are presented in Table 3. There were highly significant ($P < 0.01$) genotype x location, genotype x season, genotype x harvesting date, location x genotype x harvesting date and genotype x season x harvesting date interactions for pod shattering. The results are in agreement with earlier observations the outcome of which was a recommendation that selection for resistance to pod shattering in a breeding programme should be carried out in production areas since different varieties respond differently depending on locations (Akpan, 1988). Similar recomme-ndations were made by Philbrook and Oplinger (1989), Tiwari and Bhatnagar (1993), Helms (1994) and Bailey *et al.* (1997). Thus, for effective selection for resistance to pod shattering in soybean, testing and evaluation should be carried out at several locations over a number of seasons.

The loss associated with delayed harvesting date in kg ha^{-1} and monetary value is shown in Table 4. Maximum yield loss (186 kg ha^{-1}) and corresponding financial loss (148,800 Shillings ha^{-1}) were recorded at the third harvesting date, thus, emphasising the need for early harvesting to avoid such loss due to pod shattering. Variety TGm 737P was the most susceptible to shattering, in which 57-175 kg ha^{-1} of the total yield, equivalent to 45,600 - 140,000 Shillings was lost. Genotypes Kab 1 and Nam 1 exhibited maximum grain yield

TABLE 2. Yield loss due to pod shattering and expected total seed yield (kg ha^{-1}) of three varieties using actual and extrapolated plot yields

Genotype	Parameter#	Yield kg ha^{-1}	
		Actual field yield	Extrapolated yield ± s.e
TGm 737P	Yield loss	1650	1636 ± 116 ns
	Total yield1	1869	1922 ± 84 ns
	Total yield2		1856 ± 16 ns
Kab1	Yield loss	1197	1138 ± 70 ns
	Total yield1	2181	2239 ± 76 ns
	Total yield2		2117 ± 131 ns
Nam1	Yield loss	775	597 ± 72 ns
	Total yield1	2414	3011 ± 207*
	Total yield2		2239 ± 73 ns

* = Significant at ($P < 0.05$); ns = Non significant at ($P < 0.05$); # Total yield1 is determined from shattered pods; Total yield2 is determined from unshattered pods

TABLE 3. Combined analysis of variance for total yield loss due to pod shattering at Namulonge, Nakabango and Iki-Iki over 1997A and 1998B

Source of variation#	Degrees of freedom	Mean square
S	1	9350**
L	2	1950**
R(L)	6	25
G	2	5500**
HD	2	3819**
L x G	4	745**
L x HD	4	283**
G x HD	4	59*
G x S	2	3298**
G x S x HD	4	631**
G x L x HD	8	113**
G x S x L x HD	18	231**
Error	102	19
CV (%)		22.46

S# = Season, L = Location, R = Replication, G = Genotype, HD = Harvesting date
* Significant at $P < 0.05$; **significant at $P < 0.01$

losses of 24% and 10% equivalent to a financial loss of 148,800 and 71,200 shillings, respectively.

Genotypes TGx 1448-2E, Duiker and Nam 2 showed no loss over the harvesting period, thereby demonstrating a high level of shattering resistance. These varieties are, thus, good sources of resistance for breeding for shattering resistance. Cultivation of susceptible varieties should be avoided since they start shattering on commencement of maturity resulting into high field loss at this level. Philbrook and Oplinger (1989) observed relatively lower yield losses in the USA due to shattering than reported in this study due to milder weather conditions, which might explain why little research on soybean shattering has been done in North America. Bailey *et al.* (1997) reported that North American varieties are resistant to pod shattering, however, the case may be different when grown in tropical environments where weather conditions are more conducive to shattering.

Results for correlation between weather

TABLE 4 Mean yield loss in kg ha^{-1} and its equivalent in monetary value over 3 locations in three genotypes during 1997A[1] and 1998A, seasons

Genotype	Harvesting date	Total yield ha^{-1}	Yield loss ha^{-1}	% yield loss ha^{-1}	Monetary value (Ug Shs.[2])
TGm 737P	1	581	57	10	51,300
	2	712	145	20	130,500
	3	615	175	28	157,500
KAB1	1	775	0	0	0
	2	943	69	7	62,100
	3	777	186	24	67,400
NAM1	1	903	0	0	0
	2	983	92	9	82,800
	3	888	89	10	80,100
Duiker	1	787	-	-	-
	2	896	-	-	-
	3	995	-	-	-
Tax 1448-2E	1	915	-	-	-
	2	1002	-	-	-
	3	992	-	-	-
NAM2	1	1105	-	-	-
	2	988	-	-	-
	3	1112	-	-	-

[1]First rains of 1997 (1997A), and first rains of 1998 (1998A)

[2](1 US Dollar = 1500 Uganda Shillings)

TABLE 5. Phenotypic correlation coefficients for yield loss due to shattering and weather components for three varieties over three locations in two seasons

Weather component	Number of observations (n)	Correlation coefficient (r)
Mean daily temperature	162	0.29*
Minimum temperature	135	-0.13 ns
Maximum temperature	135	0.48*
Rainfall	162	0.08 ns
Humidity	162	-0.21 *

* Significant at P < 0.05; **significant at P < 0.01

components and yield loss are presented in Table 5. Positively significant ($P < 0.05$) correlation were observed between yield loss and daily mean temperature and maximum daily temperature indicating that high temperature enhanced shattering intensity. Correlation between humidity and yield loss was negative ($P < 0.05$) indicating that higher humidity lead to reduced pod shattering. The effect of these weather components may have accounted for the G x E interactions observed in terms of different temperatures and humidity at different locations and seasons.

CONCLUSIONS

Estimated yield losses were similar to those measured from the actual seed losses due to pod shattering. We recommend the estimation method for use in farming systems where pod shattering is spontaneous due to stress from environmental factors. It does not apply to loss caused by header of the combine during harvesting. It is proposed that studies in controlled environment be conducted to determine threshold levels of temperature and humidity on pod shattering in soybean genotypes in order to develop a more comprehensive model to be applied in determining yield loss due to pod shattering in defined environments. Such a model would be a useful tool in breeding and production of soybeans, when selecting varieties for which pod shattering does not lead to significant yield loss in given environments.

Due to the significant influence of genotype, location, season and G x E interactions on pod shattering in soybean, we recommend that selection for resistance to pod shattering be carried out in several locations in different agro ecological zones over several seasons. This is particulary important for cultivars that are cultivated over wide geographical areas.

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