Rice crop stage susceptibility to the rice yellow stemborer *Scirpophaga incertulas* (Walker) (Lepidoptera: Pyralidae)

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Abstract

From field trials with artificial infestation of rice yellow stemborer *Scirpophaga incertulas* (Walker) (YSB) egg masses over the post-transplanted crop cycle and reports in the literature, it was concluded that rice passes through three stages of general morphological resistance interceded by two stages of susceptibility. Resistance occurs on very young rice, at mid-growth, and after panicle exsertion. The resistant period at mid-growth varied by plant maturity. On an early maturing rice variety (IR72), resistance occurred from panicle initiation (PI) to pre-booting, while on the medium maturing IR70, resistance was extended from the late vegetative stage to booting. High deadheart (severed tiller) densities occurred post transplanting because, being small, up to three tillers are damaged by a single larva. Whiteheads (severed panicles) were formed from infestations from booting onwards and were relatively higher than deadhearts on the early maturing variety but relatively less on the medium maturing variety. Zinc deficiency delayed maturity of IR72, and the period of naturally high resistance of seedlings was extended throughout most of the vegetative stage as well as after PI through pre-booting. Resistance at mid-growth and after panicle exsertion could be from: (1) lignin and cellulose deposits on the cell walls, (2) tight wrapping of the leaf sheath, and (3) deposition of silica. All three trials produced similar quadratic models of the yield response to crop age when infested. Deadheart damage was compensated to a large degree, but lowest yields occurred from whitehead damage when infested at or just after the pre-booting stage.

Keywords: Rice, stemborer, damage, yield loss, morphological host plant resistance, crop age, plant maturity, zinc deficiency, insecticide decision making

1. Introduction

Larvae of the rice yellow stemborer *Scirpophaga incertulas* (Walker) (YSB) feed internally in the rice plant. Upon hatching, the first instar disperses by crawling or ballooning to locate a rice tiller to penetrate (Shiraki 1917) and if another larva is detected it will move to another tiller. Normally one larva infests a tiller. By rapidly entering rice plants, larvae are afforded protection from natural enemies and insecticides.

Their tunnelling results in the severed tillers (deadhearts) and panicles (whiteheads). The larval stadium lasts about a month depending on nutrition and temperature. Fortunately, YSB rarely achieves epidemic proportions. Due to their persisiveness and type of injury, stemborers have been most strongly associated with chronic yield loss among insect pest groups attacking wetland rice (Litsinger et al. 1987). Yield loss is more significant if it occurs synergistically with other biotic and abiotic stresses (Khan et al. 1991; Litsinger 1991; Savary et al. 1994).

Conventional breeding methods have identified breeding lines exhibiting tolerance or moderate levels of resistance, but not the high levels of chemical-based resistance that were achieved with homopteran pests (Heinrichs 1986). Morphological resistance to stemborer larvae has been long known (Djamin and Pathak 1967) but no released varieties based on this resistance have been developed. With most varieties being susceptible to stemborers, control is mainly by insecticides. Due to improper timing of applications, insecticide control is usually ineffective (Litsinger submitted).

Researchers, beginning with Shiraki (1917), have noticed that stemborer damage often varied dramatically by plant growth stage, regardless of variety. In his classic study, Shiraki noted first instar larvae readily penetrated at the panicle exsertion (PE) stage; afterwards the peduncle hardened significantly dramatically retarding entry. Subsequently other growth stages were found to offer resistance in plant-age studies based on either pot (Viajante and Heinrichs 1985; Viajante and Saxena 1988) or field (Lin Yu 1980; Viajante and Heinrichs 1987) experiments.
Field studies included no more than five growth stages.

Precise determination of the periods in the rice growth cycle when the plant confers natural resistance would be important in pest management as scouting efforts could be limited to periods when the crop is most vulnerable to damage. Zinc deficiency is common in the research site particularly in ill-drained fields (Ponnampерuma 1977). As abiotic stress such as zinc deficiency can alter the yield response in combination with insect pest damage (Litsinger 1991) we included this interaction in testing the rice crop’s ability to resist stemborers.

We investigated the natural resistance in the field more precisely than has been done before over the crop cycle. Experiments were conducted sequentially over three seasons testing: (1) a medium maturing variety the first season, (2) an early maturing variety the second season, and (3) an early maturing variety under zinc deficiency stress the third season. In each trial, the crop was artificially infested with similar densities of stemborer egg masses at weekly or bi-weekly intervals from transplanting to 3 weeks before harvest. The relative ability of each crop stage to resist YSB was determined based on damage and yield loss.

2. Methods

The trials were conducted on three farmers’ fields (one field per season) in irrigated wetland culture in Zaragoza, Nueva Ecija province, Philippines. Medium maturing IR70 (135-day variety) was tested in the 1990 dry season (DS). Early maturing (110 days) IR72 was tested both in 1990 wet season (WS) and in a zinc-deficient field (due to prolonged flooding) in the 1991 DS. Each trial was established early in the season to minimize natural pest infestation. Four-week-old seedlings were transplanted from a wetbed within each field at 6–8 seedlings per hill and 20 × 20 cm spacing between hills. The crops received urea as 30 kg N broadcast 3 w.a.t. (weeks after transplanting) followed by either 30 kg N (wet season) or 60 kg N (dry season) at panicle initiation. Crop husbandry was based on farmers’ current practices without insecticide. A pre-emergent herbicide (butachlor) was used against grasses followed by hand weeding as needed. Zinc deficiency in the first two trials was avoided by selecting well-drained fields and adding 25 kg zinc oxide in the seedbed.

Artificial infestation involved collecting YSB moths from the field, bringing them to an insectary and holding them overnight on potted rice plants inside mylar tube cages with mosquito screen vents. Egg masses were clipped from the foliage the following morning and held in petri dishes indoors until the blackhead stage to minimise natural predation. One of the major egg parasitoids is phoretic thus egg masses were inspected after removing the anal tuft covering. Parasitised egg masses were discarded. During each infestation, leaf sections bearing egg masses of normal size (80–100 eggs) ready to hatch (blackhead stage) were fastened to plants in the field with paper clips. Three egg masses were placed per 1-m² plot, distributed equidistantly for each treatment except the unin-fested check. Before the plots were infested, predators were removed by vacuum with a motorised suction machine. Each plot was sheltered for 1 week with a wooden, box-frame, 1-m³ cage with nylon mesh (0.5 mm) siding to exclude predators. Plots were separated 5 m from one another. Each trial was carried out on a farmer’s field with treatments replicated five times in a randomised complete block design.

IR72 plots were infested weekly from 1 to 9 w.a.t., while the medium maturing IR70 plots were infested at 1, 2, 4, 6, 8, 10, 12, 14, and 15 w.a.t. Two people assessed damage. One counted with the aid of a mechanical tally counter while the other recorded the results on datasheets. Mean percentage deadhearts and whiteheads were recorded from each plot by counting all damaged and undamaged tillers from each of the 25 hills weekly averaged over 2, 3, and 4 weeks (sampling dates) after infestation.

Crop stages were based on those described by Yoshida (1981). The difference between early and medium maturing varieties is the length of the vegetative stage, as the reproductive and ripening stages take approximately 30 days each regardless of variety. The crop was monitored for the timing of both panicle initiation (PI) and panicle exsertion (PE) which demarcate the boundaries between the three growth stages. A primary tiller from each of 10 hills neighbouring the plots was dissected weekly near the time of PI to determine when the panicle develops into a white feathery cone at the base of the leaf sheath. PE occurs when the panicle emerges from the swollen leaf sheath. Near PE, 10 plants were observed weekly. Both stages were determined when > 50% of plants examined reached the indicated stage.

Each plot was harvested in its entirety and the grains threshed by hand, winnowed, and air-dried to 14% moisture and weighed on a top loading electronic balance ± 0.1 g. Statistical analysis of the data was carried out by one-way ANOVA with SAS software. The data were not transformed and means were separated by the least significant difference (LSD) test with P ≤ 0.05 confidence level. As no mathematical relationship was sought on damage with crop age, the curves (Figures 1–3A) were plotted by the computer trend line to fit the points. The deadheart curve in Figure 2A was similarly fitted to the data points based on the shape in Figures 1A and 3A. Mathematical models of best fit between age of infestation and yield were analysed by regression with SAS software.
3. Results

3.1. Damage

There was insignificant damage from natural infestation due to escape by early planting in all three trials as <1% deadhearts and whiteheads occurred in the uninfested checks. With the medium maturing IR70, PI occurred at 8 w.a.t. and PE at 13 w.a.t. (Figure 1A). The initial infestation date 1 w.a.t. produced an average of 14% deadhearts with peak

Figure 1. Time series comparing (A) yellow stemborer (o) deadhearts and (■) whiteheads and (B) (•) yield based on artificial infestation of IR70, a medium maturing rice variety, 1990 dry season, Zaragoza. PI = panicle initiation stage, PE = panicle exsertion stage.

Figure 2. Time series comparing (A) yellow stemborer (o) deadhearts and (■) whiteheads and (B) (•) yield based on artificial infestation of IR72, an early maturing rice variety, 1990 wet season, Zaragoza. PI = panicle initiation stage, PE = panicle exsertion stage.
deadheart damage (20 – 22%) immediately following from treatments infested 2 and 4 w.a.t. Thereafter deadhearts rapidly declined to 8% when infested at 6 w.a.t. and to a low of < 2% when infested at 12 w.a.t. Thus, most of the deadheart damage occurred from infestation during the first half of the vegetative stage. Whitehead damage was confined to treatments infested after booting in the ripening stage which rose precipitously from treatments infested 14 – 15 w.a.t. attaining a high of 9%. The additional 3% deadhearts recorded in the treatment infested at 15 w.a.t. represented damage to secondary and tertiary tillers that were too young to produce panicles. Adding the deadhearts and whiteheads together, ripening stage damage was about half that of the vegetative stage. The low whitehead damage recorded in the vegetative and reproductive stages represented the natural infestation (Figure 1A).

With the early maturing IR72, PI occurred at 4 w.a.t. and PE at 8 w.a.t. (Figure 2A). Deadhearts rose from an initial 4% from infestation at 1 w.a.t. and peaked at 8% when infested at mid-vegetative stage (2 – 3 w.a.t.) and declined to a low of 1% by the treatments infested 7 – 9 w.a.t. Whiteheads began to rise in treatments infested during pre-booting in the late reproductive stage and peaked on the last infestation date in the ripening stage. In marked contrast to IR70, whitehead damage in IR72 was twice that of deadheart damage.

The vegetative stage of IR72 was prolonged by 2 weeks (which ended 6 w.a.t.) on zinc stressed soil and the reproductive stage was shortened by 1 week (which began 9 w.a.t.) (Figure 3A). Deadhearts produced two peaks, the first (6%) on treatments infested 5 – 7 w.a.t. (the juncture between the vegetative and reproductive stages) and the second (10%) from treatments infested 9 and 10 w.a.t. during the ripening stage. Whiteheads began to rise from infestations at the end of the reproductive stage and peaked (14%) during infestations in the ripening stage. Similar with the non-stressed trial, infestations during the ripening stage produced much more damage than infestations during the earlier stages. Both trials with IR72 had comparable damage peaks of both deadhearts (6%) and whiteheads (16%) showing infestation methodology was consistent between experiments.

3.2. Grain yield

The longer maturing IR70 grown in the dry season had the highest yield among the three crops reaching over 6 t/ha in the uninfested treatment which was statistically equal to infestations 1, 6, and 10 w.a.t. (Table I). Lowest yield, just over 4 t/ha, came from the last week of infestation (15 w.a.t.) followed by treatments infested 1 and 7 w.a.t.

IR72 was grown in the wet season with lowest yield potential (< 5 t/ha) due to the more limited solar radiation. Highest yield came from the uninfested well as treatments infested 3 and 5 w.a.t. Lowest yield again came as a result of infestation 9 w.a.t. (< 4 t/ha) followed by treatments infested 1 and 7 w.a.t.

The zinc stressed IR72 grown in the dry season allowed for recovery due to increased solar radiation thus yield potential was > 5.5 t/ha. Highest yield came from the uninfested as well as treatments
infested 5, 3 and 6 w.a.t. Lowest yield ( > 4 t/ha) came from infestation 10 and 11 w.a.t.

The best fit for the relationship between yield and crop age at infestation was the quadratic model in all trials (Figures 1 – 3B) with low yields associated with both early and late infestation. The relationships were significant in the three trials with correlation coefficients ranging from 0.720 to 0.810. Yield loss was not always directly related to damage. Whitehead damage was more important than deadheart damage in terms of yield loss indicating greater compensation in the latter. The model showed greater plant resistance during the mid-crop segment with lower yields from infestation both earlier and later.

4. Discussion

4.1. Damage

Both early and medium maturing varieties without zinc stress revealed high deadheart damage when infested within the first month post-transplanting. Peaks occurred when infested at 2 – 3 or 2 – 4 w.a.t. for both varieties. In the early maturing variety, resistance ( < 3% deadhearts) occurred between PI and pre-booting (mid-way between PI and PE). In the medium maturing variety, the period of resistance was extended both earlier (during the late vegetative stage) and later (booting). Resistance was seen in treatments infested from 4 to 7 w.a.t. (total of 4 weeks) in the early maturing variety and on treatments infested from 8 to 12 w.a.t. (total of 5 weeks) in the medium maturing variety. Treatments infested after pre-booting were again susceptible, manifested as whiteheads, reaching a peak on infestation at 9 w.a.t. in the early variety and on 15 w.a.t. in the medium variety.

The relatively low deadheart damage incidence at the first week of infestation compared to the succeeding several weeks indicated high larval mortality on the youngest seedlings. Viajante and Saxena (1988) showed that seedlings are a poor host for YSB larvae with < 5% surviving under artificial infestation. Only after seedlings reached 34 days old did significant feeding and survival occur. Plants are small on a newly transplanted crop and up to three tillers were fed upon per larva leading to high percentages of deadhearts (Shiraki 1917). At mid-vegetative stage, larvae can complete development in a single tiller.

The zinc-deficient crop grew slowly initially becoming stunted as the result of stress (de Datta 1981). The seedbed had also been established on the same zinc-deficient soil, thus the poor growing conditions extended the seedling stage. The second deadheart peak during the ripening stage was revealed as damage to the late maturing secondary and tertiary tillers. This is a normal situation as seen in the late deadhearts in the medium variety (Figure 1A), but under zinc deficiency, the tillering period was prolonged due to retarded growth (Yoshida 1981). The delayed tillers, being younger, formed deadhearts instead of whiteheads when damaged during the ripening stage.

The results show that rice cycles through three stages of resistance interceded by two stages of susceptibility. Seedlings are initially resistant to stemborer damage but become susceptible in the active tillering stage. Plants become resistant once more from panicle initiation (PI) (= maximum
tillering) to pre-booting (15 days before PE), turning susceptible again at booting, flowering, and heading. After heading the peduncle hardens and the panicle becomes resistant once again. Morphological resistance or hardening of tissues can explain the periods when damage was suppressed in the rice crop. There are at least three causes of morphological resistance based on the literature.

The first mechanism is the thickening of cell walls that naturally occur in aging cells from deposition of lignin and cellulose (Moore 1984). Thicker tissues in the culm and peduncle take longer for first instar larvae to penetrate. As the thicker tissue is of little nutritive value, first instar larvae often succumb before successful entry, thus preventing both deadhearts and whiteheads.

Second is the tightness of the leaf sheath enwrapping the culm. Lin Yu (1980) attributed the deadheart resistance in the reproductive stage to the snug wrapping of two layers of the leaf sheath. On the other hand, when the flag leaf is present at booting, the leaf sheath opens to allow the panicle to exsert, which also provides ease of entry to YSB larvae with the result of high whitehead damage.

A third cause is hardening of plant tissues from the deposition of silica (SiO₂). Silicon (Si) is not an essential element for plant nutrition but does provide rigidity to the rice plant and protection against biotic and abiotic stresses (Kaufman et al. 1985; Savant et al. 1997). Rice is one of the most active accumulators of silica among all plants and as a result silicon may constitute from 5 to 20% of dry weight. When silica-containing material such as slag was applied to the field as a soil amendment, stemborer resistance increased compared to untreated plots (Sasamoto 1960). Si is absorbed in the form of monosilicic acid that polymerises into biogenic opal (amorphous SiO₂·nH₂O) in leaf sheaths and culms. Such morphological resistance to boring by stemborer larvae prevents both deadhearts and whiteheads (Djamin and Pathak 1967). But as they point out, it is not the concentration of Si in the plant that is important but the distribution of Si-bearing cells along the culm. It is notable that active silica absorption starts after tillering or stem elongation (late vegetative stage) (Savant et al. 1997). This is precisely when a decline in deadhearts was noticed in the study.

But studies have shown that this natural resistance can be reduced by the uptake of nitrogen (Litsinger 1994). Nitrogen causes rapid growth particularly when applied as inorganic fertiliser. A growth spurt results from the rapid infusion of nitrogen which has the effect of making the tissue soft. The soft tissue is the result of new cell growth and elongation of existing cells that produce wide separations between Si bodies. As a result, first instar larvae not only penetrate more easily but nitrogen increases food quality, enhancing their survival.

The early post-transplanting vegetative stage is highly susceptible to penetration and feeding by YSB larvae as the plant tissues lack morphological defence due to minimal deposition of silica, lignin, and cellulose. Hardening begins at mid-vegetative stage which along with a thicker leaf sheath wrapping dramatically reduces deadhearts. Only before the panicle exserts does the rice plant again become susceptible as the protective leaf sheath wrapping is loosened and the elongating peduncle turns soft until deposition of hardening agents can occur.

4.2. Grain yield

Whitehead damage was more clearly related to higher yield loss than deadheart damage. In all three trials, lowest yields came from infestation at and after the pre-booting stage regardless of plant maturity. It should be noted that infestation was stopped before the last resistant stage, peduncle hardening of the panicles. Highest yields were not directly associated with the stages with least deadheart damage. In the trials without zinc deficiency, least damage occurred from infestations 5 and 6 w.a.t. on the early maturing variety and 8, 10 and 12 w.a.t. on the medium maturing variety (Table I). These treatments were among the highest yielding infestation dates but other infestation dates that resulted in high deadheart damage gave equivalent yields. It has been shown that rice can overcome stemborer damage by compensation particularly in the earlier growth stages especially when there are few other stresses and crop management is good (Litsinger 1991, 1993; Rubia et al. 1996). For example, it was found that many infested treatments had significantly similar yields as the uninfested treatments.

It was surprising, therefore, that infestations during the first 2 weeks in all three trials did not lead to highest yields and thus the best fit was the quadratic model. But a newly transplanted crop is under stress from the loss of rootlets and root hairs during pulling of the seedlings, termed transplanting shock. The combined stress of transplanting shock and stemborer damage could be the reason for the low yields from early infestation. The low yield in the zinc stressed trial at the first stage of the crop with minimal stemborer damage (Figure 3B) may have been related to both zinc stress and transplanting shock.

Experience has shown that YSB populations are usually lowest during the post-transplanting period. Therefore, although the potential for damage is high in the early vegetative stage, YSB generally does not begin to reach significant densities in the field until the late vegetative stage. It is to be noted that direct seeded rice would have avoided transplanting shock and the yield response curve likely would be different. Higher degrees of compensation have been found to occur in long maturing cultivars (Litsinger et al. 1987), although that was not deducible in this study as varieties were not tested side by side.
The results show that when using action thresholds, the crop does not need to be monitored for stemborers nor should insecticide be applied from PI to pre-booting on early maturing varieties or from the late vegetative stage to booting on medium maturing varieties. This should result in labour and cost savings.

Our results also show problems that would occur in host plant resistance studies that compare varieties of different maturities. If, for example, both early- and medium-maturing varieties were being compared (Figures 1 and 2) and both were infested 5 w.a.t., one would conclude that the earlier maturing variety was more resistant (2 vs. 16% deadhearts) when in fact the longer-maturing variety would produce the same deadheart differences if infested 9 and 5 w.a.t. Thus when comparing varieties for resistance they should be grouped by maturity classes.

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References