STUDIES ON THE BIOLOGY AND ECOLOGY OF PAGIOCERUS FRONTALIS (FABRICIUS) (COLEOPTERA: SCOLYTIDAE) INFESTING STORED MAIZE IN ECUADOR

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Abstract

In laboratory experiments hosts, host-related behaviour and the effect of temperature and relative humidity on the development of *P. frontalis*, the major pest of stored maize in the Andes of Ecuador, were investigated.
Attemps to rear the species on different cereals and leguminouses, *Chenopodium quinoa, Persea americana, Anona cherimola,* eucalyptus and laurel wood, coffee and ground maize showed, that besides maize grain avocado seeds provided the only adequate diet for oviposition and development. On maize, the number of F_1-adults that emerged from soft varieties was higher than from harder, flintier grains, but even popcorn was not immune to attack. Rate of reproduction and weight losses did not differ between shelled grain and maize on cobs.
The minimum duration of the life cycle from egg to adult on soft maize at 23°C and 90 or 60% r.h. was 21.7 and 25 days, respectively, after a preoviposition period of 2 and 2.3 days. The number of emerged adults (F_1) was significantly reduced at 60% r.h. Lower temperatures increased the duration of the life cycle up to 26.5 days at 16°C after 5.5 days of preoviposition. The highest number of emerged F_1-adults was observed at 20°C and 80% r.h. At 10°C oviposition was prevented.
Rearing temperature and diet did not affect the proportion of females to males, which corresponded to the theoretical 1:1 ratio.
The longest survival period of an individual adult was 223 days on soft maize.

Introduction

The distribution of *Pagiocerus frontalis* reaches from the Southern USA across Central America and the Caribbean to South America (Schedl, 1965), but its importance as a serious pest of stored maize has been reported only from the highland of the Andes in Ecuador, Peru, Chile and Colombia (Yust, 1957, Gloria, 1972, Gómez and Aguilera, 1982, Saldarriaga, 1985). Infestation of cobs usually starts in the field before harvest and continues throughout storage where the maize often is destroyed within three or four month (Yust,1957).
P. frontalis has been known to breed only on unshelled maize (Wichmann, 1954, Heinze, 1983), and Saldarriaga (1985) confirmed that populations of a colombian strain increased faster when reared on maize on the cob than on loose grain. In Ecuador large soft maize appears as the only substrate of *P. frontalis* (Yust, 1957), whilst in other regions it is recorded also from the seeds of five species of Lauraceae including *Persea americana,* two species of Annonaceae and one of Boraginaceae, as well as from coffee beans and coffee cherries (Wille, 1943, Schedl, 1965, Atkinson and Martínez, 1985). On maize varieties with a hard endosperm reproduction of the scolytid is prevented (Beccari, 1963, Gómez and Aguilera, 1982) or considerably reduced (Saldarriaga, 1985).

The objective of the experiments reported here was to screen a range of stored commodities as well as different maize varieties as possible supplementary hosts of *P. frontalis* in Ecuador. Another experiment was devised to investigate the influence of the presentation of maize, since the vulnerability may differ on cobs and on shelled grain.
Aspects of the biology of *P. frontalis* in Ecuador were first studied by Yust (1957). The author recorded a total length of life cycle from adult to adult under ambient climatic conditions of about 46 days. However, investigations from Chile and Colombia have shown that the species has the potential to develop much more quickly (Gómez and Aguilera, 1982, Saldarriaga, 1985). From general observations it appeared that females deposit about 80 eggs in the maize kernels, the maximum lifespan of the adults did not exceed 102 days (Yust, 1957).
In Ecuador *P. frontalis* is reported throughout the mountain region in altitudes between 1500 and 2600 m with average temperature ranges from 14 to 18.5°C. Little information was available concerning the effect of abiotic factors on the vital processes of the storage pest. The study described here was initiated to investigate adult *P. frontalis* reproduction rate, longevity and sex ratio as well as the development period in consideration of temperature and relative humidity.

Materials and Methods

The *P. frontalis* strain used in this study was obtained from infested soft maize of a granary in a northern province in the ecuadorian highlands. Stock cultures were started 9 months before the experiments and maintained on soft maize grain in the laboratory at 17-20°C and 65-85% r.h. Only 2-4 days old newly emerged adults of unknown sex from the cultures were used for the tests. Experimental units were generally glass jars of about 700 ml closed with muslin in four replicates. Daily recorded experimental temperature and relative humidity in the laboratory ranged from 17-20°C and 70-85% (tests 1-3) or was maintained constantly in climate chambers (test 4). Prior to use the grains were always equilibrated for at least three weeks at the test conditions. If not stated otherwise data were analysed statistically by one factorial analysis of variance and by Tukey's Honestly Significant Difference Test for mean separation.

1. Survival and breeding on different food crops and wood

Eighteen different substrates including important food crops and wood used in construction were selected for the experiment: soft summer wheat, barley, oats, quinua (*Chenopodium quinoa*), haricot beans, broad beans, peas, lupines, lentils, cherimoya seeds (*Anona cherimola*), coffee beans and cherries, avocado seeds and fruits (*Persea americana*), eucalyptus and laurel wood as well as soft maize grain and ground soft maize. Wood pieces of about 1 cm^3 and the other substances except coffee cherries and avocado fruits were left on plastic trays for three weeks at an average temperature of 18.9 ± 2.2°C and a humidity of 78 ± 8%. Four replicates of 100 g of each commodity were then infested by 25 adults. The jars were kept under the conditions described above for 90 days. Mortality of exposed adults was recorded daily in all commodities and compared with the survival period of 25 adults under starvation conditions. Emerged adults were removed on alternate days until completion of emergence and the number of progeny produced was noted. The sex of 100 F_1-adults per replicate selected at random was determined by dissection of

genitals as no external characteristics were observed to distinguish easily between the sexes.

2. Breeding on different maize varieties

Six local ecuadorian highland varieties purchased from the market were selected: large, floury yellow and white soft maize, yellow, white and reddish harder, flintier maize and very flinty popcorn. After equilibration of the undamaged grains 100 g of each type were infested by 100 adult *P. frontalis* and kept at a mean temperature of 18.5 ± 2.3°C and relative humidity of 79.3 ± 8%. Mortality of exposed adults in the different commodities until removal after four weeks did not exceed 4% and was not taken into account. Emerged adults were removed daily until emergence was completed. Grains were then sieved (3 mm mesh), weighed again and the losses of weight were estimated after correcting for changes in the weight of uninfested controls.

3. Influence of the presentation of maize

Maize cobs of a local ecuadorian variety with yellow, floury, undamaged grain, each weighing about 125 g were chosen for the experiment. Four cobs without husks and loose kernels of another four shelled cobs were placed separately in glass jars prior to infestation by 50 adult *P. frontalis*. All jars were kept at a mean temperature of 18.9 ± 2.2°C and relative humidity of 78 ± 8%. Exposed adults were left in the jars until emergency of offspring was recorded 27 days after original infestation. Emerged F_1-adults were removed daily for the period it would take for the most recently laid eggs to reach the adult stage. Cobs were then shelled carefully in order not to produce more dust and after sieving oft all loose particles the percentage weight loss was calculated by the counting and weighing technique (Anon, 1969) that includes separating, counting and weighing damaged and undamaged grains.

4. Influence of temperature and relative humidity

Experimental temperatures of 10, 13, 16, 20 and 23°C (to within ± 0.8°C) were provided by thermostatically controlled cabinets and chambers. Relative humidities of 80 ± 4% at 10, 13, 20°C and of 70 ± 3% at 16°C, respectively, were maintained by water despersion. Because of limitations of equipment only two different humidity ranges (60 and 90 ± 3%) were achieved at 23° by taking advantage of natural conditions and of water despersion.
100 g of yellow soft maize were infested by 100 adult *P. frontalis* for recording the reproduction rate after 25 days of oviposition. This was obtained by daily removal of emerged F_1-adults beginning at emergence. After completion of emergence the weight losses attributable to insect attack were calculated for the maize following sieving off all dust, weighing and correcting for changes in the weight of uninfested controls. The sex of 100 emerged adults per replicate selected at random was determined after dissection of insects in all treatments (except 23°C, 90% r.h.). The survival period was calculated for the originally exposed parent adults at 10, 13, 20 and 23°C and 60% r.h. For that purpose live adults were transferred to fresh corn every 25 days until death of all individuals. Since adults showed little inclination to leave the grain before overcrowding but responded to warmth a bulb was carefully used for removing the exposed individuals. Mortality was recorded every two days.
An additional experiment was performed in order to determine the minimum development period under the following temperature and humidity ranges: 16°C (70% r.h.), 20°C (80%), 23°C (60 and 90%). To avoid disturbance and in-

jury of larvae of the first instars, which had little chances of survival outside the grains, only whole kernels were used for the experiment. 150 maize grains placed in glass jars of about 250 ml were infested heavily with 300 adult *P. frontalis* in 6 replicates. The minimum time taken to reach the different development stages was estimated by daily removal and examination of five bored kernels. In each case the most advanced stage was noted. Exposed adults were taken out when oviposition could be observed in all replicates.

Results

1. Survival and breeding on different food crops and wood

The mean survival period of adult *P. frontalis* on wheat, barley, oats, quinua, leguminouses, cherimoya and coffee seeds ranged from 2.9 to 6.9 days and did not differ significantly from the mean longevity of adults under starvation conditions which was 4.9 days. Also wood pieces did not comply with the nutrition demands of the pest, as it is known for other scolytids. On coffee cherries, avcado fruits and on ground maize adults subsisted for 15.0, 16.9 and 49.3 days, respectively, and few individuals were still alive after 24, 33 and 90 days, but under no circumstances the test commodities provided an adequate diet for oviposition and development. Insect attack and damage due to boring but generally negligible was observed in all materials except barley, quinua and peas.
The ability to breed was recorded only for maize grain and avocado seeds, where mortality of exposed adults did not exceed 2 and 8% until emergence of offspring 27 days after initial infestation. The mean number of F_1-adults that emerged within 30 days was much lower for the maize (242.8) than for the avocado seeds (335.8), but comparison of the data (t-test) showed that there was no significant difference in the rate of reproduction between both diets. The proportion of females in the emerged adults was 0.55 (maize) and 0.54 (avocado) and did not differ from the theoretical 1:1 ratio of males to females (chi-square-test).

2. Breeding on different maize varieties

The ability of adult *P. frontalis* to breed could be observed for all selected varieties. Emergence of offspring began 28 (soft maize), 32 (hard maize) and 42 (popcorn) days after initial infestation and was completed within 32, 37 and 48 days, respectively. The total number of offspring on the harder, flintier varieties (967.25, 938.75 and 861.5 F_1-adults) was significantly ($\alpha \leq 5\%$) lower than on the soft maize (1418.25 and 1300 F_1-adults). On popcorn, where the build up of a population was largely reduced, the rate of reproduction (75.5 F_1-adults after 90 days) differed significantly from all other varieties (Figure 1). The same graduation with equal significant differences (at $\alpha \leq 5\%$) was observed for the weight losses, where highest values were recorded for yellow and white soft maize (43.4 g and 38.75 g, respectively). Resulting in 26.85 g (flint yellow maize), 28.23 g (flint white maize) and 25.83 g (red flint maize) it appears that also the attack of the harder varieties produced considerable losses. For popcorn, a weight loss of 8.23 g was calculated. A positive correlation ($r=0.98$) was found between weight losses in grains and the total number of emerged adults.

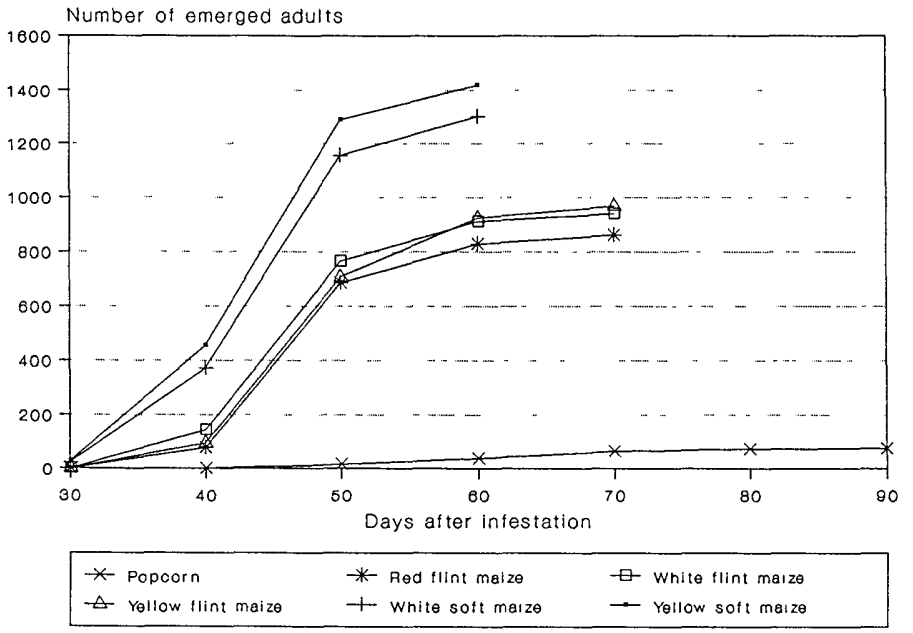

Figure 1: Total number of adult *P. frontalis* emerged in six stored maize varieties after infestation by 100 unsexed adults

3. Influence of the presentation of maize

58 days after initial infestation weight losses reached 21.8% on maize cobs and 20.5% on loose maize. The mean number of progeny produced was 720.25 and 720, respectively. Comparison of data obtained (t-test) showed that maize on the cob did not suffer higher weight losses than shelled grain and that grain texture did not influence the emergency of offspring.

4. Influence of temperature and relative humidity

Emergence of F_1-adults was observed 25 (23°C, 90% r.h.), 27 (23°C, 60% r.h. and 20°C), 32 (16°C) and 47 (13°C) days after initial infestation and was completed within 29, 32, 37 and 52 days, respectively. The highest number of progeny and the highest weight losses for the maize were obtained at 20°C and 80% r.h., but did not differ significantly from the data recorded at 23°C and 90% r.h. High temperature and low humidity (23°C, 60% r.h.) as well as low temperature (13°C, 80% r.h.) resulted in a decisive reduction of the total number of adults emerged and of weight losses. At 10°C, 80% r.h. oviposition and development was prevented (Table I).

Table I: Total number of adult *P. frontalis* emerged and corrected weight losses occuring at different temperatures and humidities after infestation by 100 unsexed adults

Treatment temp. (°C)	r.h. (%)	Days after infestation 30	40	50	60	70	80	90	100	total	weight loss (g)
10	80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	---
13	80	0.00	0.00	1.75	19.75	80.25	243.25	338.25	362.75	362.75 c''	19.38 bc''
16	70	0.00	255.00	552.00	793.25	818.00				818.00 bc	24.00 bc
20	80	45.50	406.50	1266.25	1492.50					1492.50 a	45.90a
23	60	73.50	144.00	220.50	233.00					233.00 c	16.30 c
23	90	557.75	1012.00	1117.50	1129.75					1129.75 ab	38.23ab

* = Tukey's Honestly Significant Difference Test at $\alpha \leq 5\%$
** = Tukey's Honestly Significant Difference Test at $\alpha \leq 1\%$

The proportion of females in the number of adults emerged was 0.55 (13°C), 0.54 (16°C), 0.49 (20°C) and 0.51 (23°C, 60% r.h.). A chi-square-test indicated that the sex ratio was not significantly affected by the different physical environments and that a 1:1 ratio of males to females can be suggested.
The mean survival period for the exposed parent adults was 49.8 days at 10°C (max. 125 days), 102.2 days at 13°C (max. 223 days), 91.4 days at 20°C (max. 189 days) and 75 days at 23°C, 60% r.h. (max. 205 days) with significant differences between the lowest temperature and all other environments as well as between 13°C and 23°C, 60% r.h. ($\alpha \leq 1\%$).
The minimum duration of development from egg to adult occured significantly more quickly at 20°C, 80% r.h. and 23°C, 90% r.h. than at 16°C and 23°C, 60% r.h. At 16°C the preoviposition period was significantly extended (Table II). Newly emerged adults required at least another two days for completing sclerotisation and obtaining complete mobility.

Table II: Mean minimum preoviposition and development periods from egg to adult (days) of *P. frontalis* at different temperatures and relative humidities

	Treatments (temperature, rel. humidity) 16°C 70%	20°C 80%	23°C 60%	23°C 90%
preoviposition	5.50 a**	2.50 b	2.33 b	2.00 b
eggs	6.00 a*	5.00 a	5.33 a	5.17 a
larvae	15.67 a**	13.33 b	14.50 ab	12.00 c
pupae	4.83 a*	4.67 a	5.17 a	4.50 a
egg to adult	26.50 a**	23.00 b	25.00 a	21.67 b

* = Tukey's Honestly Significant Difference Test at $\alpha \leq 5\%$
** = Tukey's Honestly Significant Difference Test at $\alpha \leq 1\%$

Discussion and conclusions

The results presented here demonstrate that *P. frontalis* is capable to damage a wide range of materials by boring. Additional observation has shown that even plastic petri dishes can be bored. On coffee cherries, avocado fruits and on ground maize subsistence for longer periods is possible. Among all tested materials, however, the species is only able to breed successfully on maize grain and avocado seeds. Other reported hosts such as coffee beans and coffee cherries (Wille, 1943) possibly correspond to another species of the genus *Pagiocerus*, as it was reported from El Salvador (Lipes, 1968). In Ecuador, where the cultivation of avocado trees is common in parts of the soft corn growing area, infestation of seeds of fallen avocados might be of some importance in the build up of populations.

Varietal differences in the hardness of maize grain appeared to have a lesser effect on the reproduction of the scolytid than it was expected in view of earlier observations by Gómez and Aguilera (1982) and Saldarriaga (1985). Although the highest rate of reproduction and highest weight losses were recorded for soft maize, *P. frontalis* also developed well on the harder, flintier varieties.

In Ecuador, *P. frontalis* is a serious pest in areas where maize is stored mainly on the cob. There was no evidence that the method of presentation of maize grain may affect its susceptibility to *P. frontalis*. The scolytid appears to grip kernels easily, in contrast to *Prostephanus truncatus* (Horn) (Coleoptera: Bostrichidae), which apparently needs to brace itself against something that is fixed relatively to the boring target (Cowley *et al.*, 1980).

P. frontalis, a species of almost temperate climates, prefering lower temperatures (Sarmiento and Díaz, 1982), retains the ability to develop successfully and even more quickly at higher temperatures such as 23°C, if relative humidity is maintained at a high level. Low atmospheric moisture of 60% at 23°C has an adverse effect on the rate of reproduction and the duration of the development period. On the other hand Wille (1934) observed a prompt breakdown of *P. frontalis* cultures in high environmental humidities. Also temperatures as low as 13°C adversely affect the reproduction rate and extend the time needed to complete development, while longevity of adults remains unaffected. The scolytid is known to be very susceptible to coldness (Wichmann, 1954), but even at 10°C, where development was prevented, adults subsisted for up to 125 days. Concerning the reproduction rate, temperatures of about 20°C appear to have beneficial effects.

Analysis of the overall results showed that in temperature and humidity ranges normally found in soft maize storage regions of Ecuador *P. frontalis* has the potential to develop more quickly than stated in previous investigations by Yust (1957). Temperature and humidity requirements as well as nutrition demands do not appear as the only responsible factors for the absence of the species from maize growing areas in warmer climates in Ecuador.

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ETUDE DE LA BIOLOGIE ET DE L'ECOLOGIE DU *PAGIOCERUS FRONTALIS* (FABRICIUS) (COLEOPTERA : SCOLYTIDAE) PARASITANT LES STOCKS DE MAIS DE L'EQUATEUR

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RESUME

Nous avons étudié en laboratoire le comportement d'hôtes expérimentaux par rapport aux effets de la température et au degré d'humidité relative sur le développement de *P. frontalis*, un des principaux déprédateurs des stocks de maïs des Andes de l'Equateur.

Des élevages de l'espèce sur différentes céréales et légumineuses (*Chenopodium quinoa*, café, avocat et *Anona cherimola*) ont montré, qu'hormis les grains de maïs, seules les graines d'avocat fournissaient un régime approprié au développement et à la ponte. Chez le maïs, le nombre d'adultes sortis des variétés tendres s'est avéré plus élevé que chez le maïs à grains à coeur dur, et même le pop-corn n'était pas immunisé contre l'infestation. Le taux de reproduction et les dégradations n'étaient pas différents entre les grains en gousses et le maïs en épi.

La durée du cycle de vie allant de l'oeuf à l'adulte sur la maïs tendre à 23° C, 90 et 60 % RH après une période avant ponte de 1 jour était, de 22,7 et 26 jours, respectivement . Le nombre d'adultes nés (F1) était nettement réduit à 60 % RH. Des températures plus basses ont augmenté la durée du cycle de vie jusqu'à 27,5 jours à 16° C après une période avant ponte de 4,5 jours. Le taux le plus élevé d'adultes F1 était observé à 18-20° C et 8,0 % RH. La ponte a été supprimée à 10° C. L'alimentation et la température d'élevage n'ont pas affecté le rapport mâles-femelles qui était de 1,1 : 1.

Le période de survie la plus longue chez un individu adulte a été de 224 jours sur maïs tendre.