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Effect of post-harvested rice conservation on *Sitophilus oryzae* L. in Côte d'Ivoire

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ABSTRACT: Harvested rice in rural area in Côte d'Ivoire is stored under four main modalities: Husked and Not Parboiled Rice (HNPR), Husked and Parboiled Rice (HPR), Not Husked and Not Parboiled Rice (NHNPR) and Not Husked and Parboiled Rice (NHPR). The effect of rice treatments on *S. oryzae* population dynamics was thus assessed based on parameters such as the number of living individuals counted at each observation period, the evolution of the population biomass, the evolution of the cumulative percentage of mortality over time and depending on sex. Laboratory studies on some population dynamics parameters of *Sitophilus oryzae* L. (Coleoptera : Curculionidae) depending on these four rice conservation modalities, showed that only the (HNPR) treatment allowed a significant population growth and an important increase of the living biomass of this pest. In addition, high *S. oryzae* mortality rates were observed when the insect was reared on the three other rice conservation modalities. Besides, more than 50% of insect parents died during the first forty five days of the tests when the insects were reared on HPR, NHNPR and NHPR. These results will allow the conception of non-chemical management methods based on the bioecology of this pest.

***Keywords*:** Insects, Population, Mortality, Resources, Rice processing

INTRODUCTION

The rice weevil *Sitophilus oryzae* L (Coleoptera: Curculionidae) and the insects of *Sitophilus* genus are polyphagous pests causing significant losses in stored cereal grains (Appert, 1985; Cruz et al., 1988; Agbaka, 1991; Delobel and Tran 1993; Bienvenido , 1994; Kra, 2001; Yoboué, 2001, Doumbia et al., 2014a, Doumbia et al., 2014b). This insect can greatly compromise the economic income of rice producers because local rice storage conditions are not always appropriate. In Côte d'Ivoire, harvested rice is stored in various processing aspects (paddy husked or parboiled grains) and various conditions (bags or granary). In order to efficiently control and manage *S. oryzae* in stored rice in rural areas, it is therefore important to understand how the insect population performs under the different various processing aspects or storage facilities.

It is important to understand how these insects behave and perform in a given environment depending on the resource available (Doumbia, 1998).

In any given environment, an animal must behave optimally to get the most possible energy in order to survive and contribute effectively to future generations (Pyke, 1984). In insects, this notion of optimality is quantifiable in terms of mass gain (living biomass), number of viable offspring produced and mortality rate in specific environmental contexts. These parameters are influenced by the resources' quality, quantity, availability and accessibility

(Pickford, 1962; Howe and Currie, 1964; Chippendale 1972; Ali, et al., 1972; Macfarlane and Thorsteinson, 1980; Begon et al., 1996). The rice preservation conditions should thus have an impact on the population dynamics of *S. oryzae.*
The objective of this study is to investigate the effect of grains states and storage conditions on gain, losses and and *S. oryzae* population growth and mortality. This information will provide a better understanding of the population dynamics of the pest for an efficient pest management strategy under different storage conditions. The impact of a resource on an animal species can be achieved by measuring the variation in the number of individual species over time, the variation in living biomass and the mortality rates within the population (Schoener, 1971; Pulliam, 1974; Hamalainen and Loschiavo, 1977; Pyke, 1984; Campbell, 2002).

MATERIALS AND METHODS

2.1. Insect Rearing
The insects used in the trial came from laboratory culture of *S. oryzae*. The culture consists to keep insects in 1 litter glass jars containing milled rice and covered with muslin. These jars were kept in the dark condition at 29 ± 2 °C and 75 ± 5% r.h. These conditions are favorable for the developmental of *S. oryzae* (Longstaff, 1981). Every second day, the rearing jars were removed from the sterilizer and their content was screened; adults were removed and put into clean rearing jars.

2.2. Rice processing
The Bouaké 189 rice variety from WARDA (West Africa Rice Development Association) used in this work came from Dabou, location 50 km from Abidjan (Côte d'Ivoire), where this variety is widespread. Four treatments were performed - Husked and Not Parboiled Rice (HNPR), Not Husked and Not Parboiled Rice (NHNPR), Husked and Parboiled Rice (HPR), Not Husked and Parboiled Rice (NHPR) corresponding to the four storage condition where rice is submitted prior to the selling or consumption. In this experiment, dried paddy rice sample, was taken from the field. Half of this sample was parboiled: the rice was placed in hot water in a drum of ten liters for 48 hours. After this period, it was removed from the drum, spun and then treated with vapor on a covered metal sieve placed over a pot containing water heated by wood fire. Rice was considered well parboiled when the envelope of certain grains cracked. The rice thus treated was then dried out for five days. Half of the parboiled and not parboiled rice was then husked with a grinder and half of them was kept as they are. So we obtained four different treatments that were: Husked and Not Parboiled Rice (HNPR), Not Husked and Not Parboiled Rice (NHNPR), Husked and Parboiled Rice (HPR), Not Husked and Parboiled Rice (NHPR).

2.3. Impact of rice treatment on the population dynamics of the rice weevil
Adults *S. oryzae* collected from the culture stock were sexed under a stereo microscope at 40X magnification (Delobel and Tran, 1993), and 10 males and 10 females from five to seven days old were placed together in a glass jar (137 ml) containing 50 g of rice from one of the treatment mentioned above. Each treatment was replicate 5 times. These jars were then placed in the dark in a sterilizer at 29 ± 2 °C, and 75 ± 5% r.h. Every 15 days for 180 days, the number of living insects in each treatment were counted and weighed (Sartorius precision 10^{-4} g), and the dead insects were counted and sexed.
The cumulative proportion of dead insects from the beginning of the experiment until the end of observations at 180 days was determined for each mode of rice storage and for each observation period using the following formula:

$$\mathbf{MC_t\ (\%)} = \frac{\sum_0^t m}{MC_{180}} \times 100$$

MC_t (%) = Cumulative percentage of dead individuals during the observation period t;
$\sum_0^t m$ = Sum of actual mortalities from 0 to t days (0 days ≤ t ≤ 180 days);
MC_{180} = Cumulative number of dead individuals at 180 days.

2.4. Statistical analysis
A Generalized Linear Model (GLM) was used with three factors: sex, rice treatment and time. The principal effects as well as the interaction between factors were tested by HSD post hoc Tukey test at P = 0.05. All analyses were conducted using Statistica 7.1. for Windows (StatSoft, 2005).

RESULTS AND DISCUSSION

3.1. Effect of rice treatment on the population size
Rice treatment (F = 132.8; d.f. = 3; P < 0.0001), time (F = 29.9; d.f. = 11; P < 0.0001) and their interaction (F = 56,54; d.f. = 33; P < 0.0001) had highly significant effect on the population size in the jar ; the population in the HNPR treatment was the only treatment with alive individuals at the end of the experiment (180d).
This study highlights the impact of the quality of the resource on *S. oryzae* population growth, biomass, number of individuals and mortality. The overall result demonstrated that HNPR was the most suitable resource for *S. oryzae* as both the biomass and the number of living individuals were higher, and the mortality was lower. In addition, HNPR was the only resource for which the population was still present after 180 days.
HNPR, commonly known as brown rice (Bienvenido, 1994), has a higher protein content, minerals and vitamins, and a part of these nutrients are concentrated in the bran layers (Barber, 1972; Resurreccion et al., 1979; Eggum et al., 1982). All of these nutrients, especially carbohydrates (starch endosperm) are very favorable to the survival of *S. oryzae* adults (Chippendale, 1972). In addition, the texture of HNPR is tender externally, making it more accessible for *S. oryzae* female in search of feeding and nesting sites. Moreover, gaps in the intercellular spaces of the endosperm of HNPR are favorable to *S. oryzae* larval development (Coffman and Juliano, 1987).

3.2. Effect of rice treatment on biomass
Rice treatment (F = 131.17; df = 3; P < 0.0001) as well as time (F = 29.98; df = 11; P < 0.0001) had highly significant effect on the total biomass of the population (Figure 1). The interaction between these two factors was also significant (F = 55.8; df= 33; P < 0.0001). The post hoc Tukey test revealed that *S. oryzae* living biomass was significantly higher in the HNPR compared to other forms of rice storage only from 75 days to 180 days (P < 0.0001). *Sitophilus oryzae* living biomass decreased sharply in the NHNPR after 15 days reaching virtually zero after 30 days (Figure 1). There was no significant difference between biomass in NHNPR and NHPR (P = 0, 50), in NHNPR and HPR (P = 0.82), in NHPR and HPR (P = 0.94).

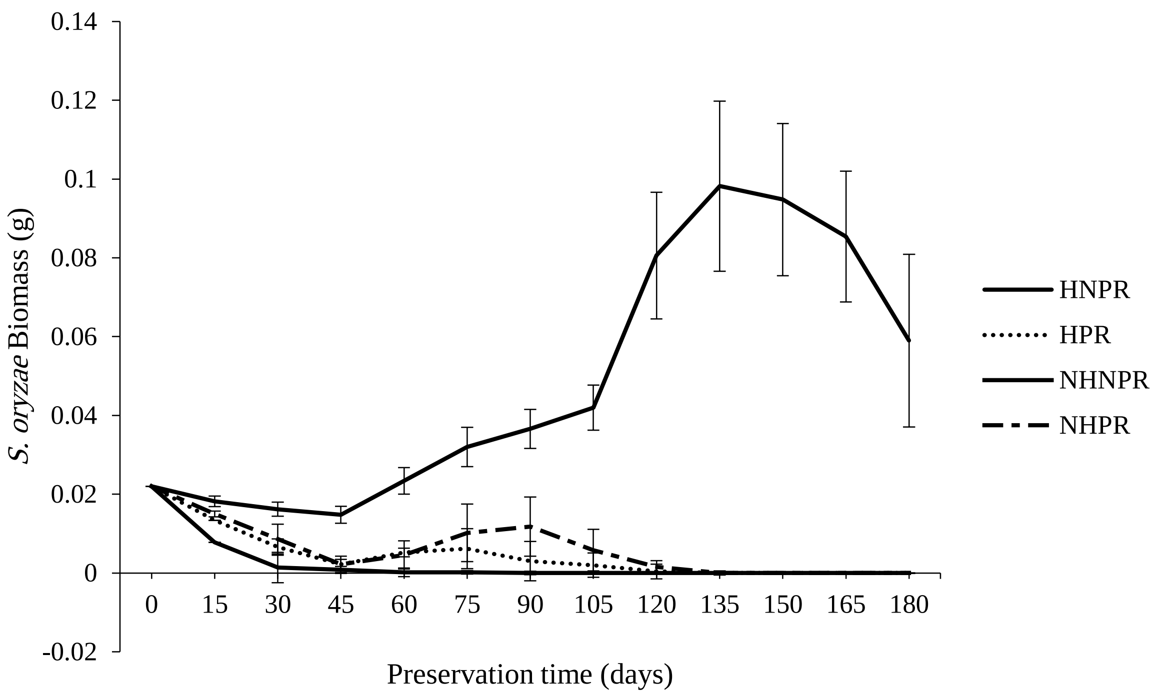

Figure 1: *S. oryzae* biomass in different rice treatment

NHNPR seems to be the least suitable resource for *S. oryzae* populations as both the biomass and the number of living individuals quickly decreased, and the cumulative mortality quickly increased. In addition, HNPR was the only treatment in which no increase in biomass and number of individual occurred after 45 days, suggesting no offspring production. The maintenance functions and reproduction in an animal determines its contribution to future generations (Bazzaz et al. 1987; Roff 1992; Begon et al., 1996), and in *S. oryzae,* this contribution to the next generations depends on their abilities to exploit the grains' physical and chemical characteristics (Campbell, 2002). Both Campbell's (2002) results and ours allow concluding that NHNPR presents very inadequate physicochemical characteristics for the survival and development of *S. oryzae* populations. Our results are similar to those of Subedi et al. (2009) who have shown that polished rice was the most preferred host in free-choice testing by *S. oryzae*, with 18.75% grain damage, 14.11% grain weight loss, and 138.8 adult F1 progeny while the rough rice (i.e. NHNPR) was the least preferred host. NHNPR is actually an unavailable resource for *S. oryzae* because of the protective shell or bullet of the rough rice grain, in addition to a very poor source of protein and a very low energy value (Bienvenido, 1994). This explains the fact that this form of rice conservation does not ensure the survival and reproduction of *S. oryzae* individuals, leading to total extinction of the population after 75 days of trial.

3.3. Effect of rice treatment on cumulative mortality

Rice treatment (F = 25.5; df= 3; P < 0.0001), time (F = 187.91; df= 10; P < 0.0001) and the interaction between these two factors (F = 13.35; df= 30; P < 0.0001) had highly significant effect on the cumulative mortality of *S. oryzae* (Figure 2). The post hoc Tukey test revealed highly significant differences between the HNPR and other forms of rice storage (P < 0.0001); insects died earlier on NHNPR, with a large majority of individuals dead after only 30 days on NHNPR. Moreover, the cumulative mortality of *S. oryzae* was not statistically different between the HPR and NHPR (P = 0.813).

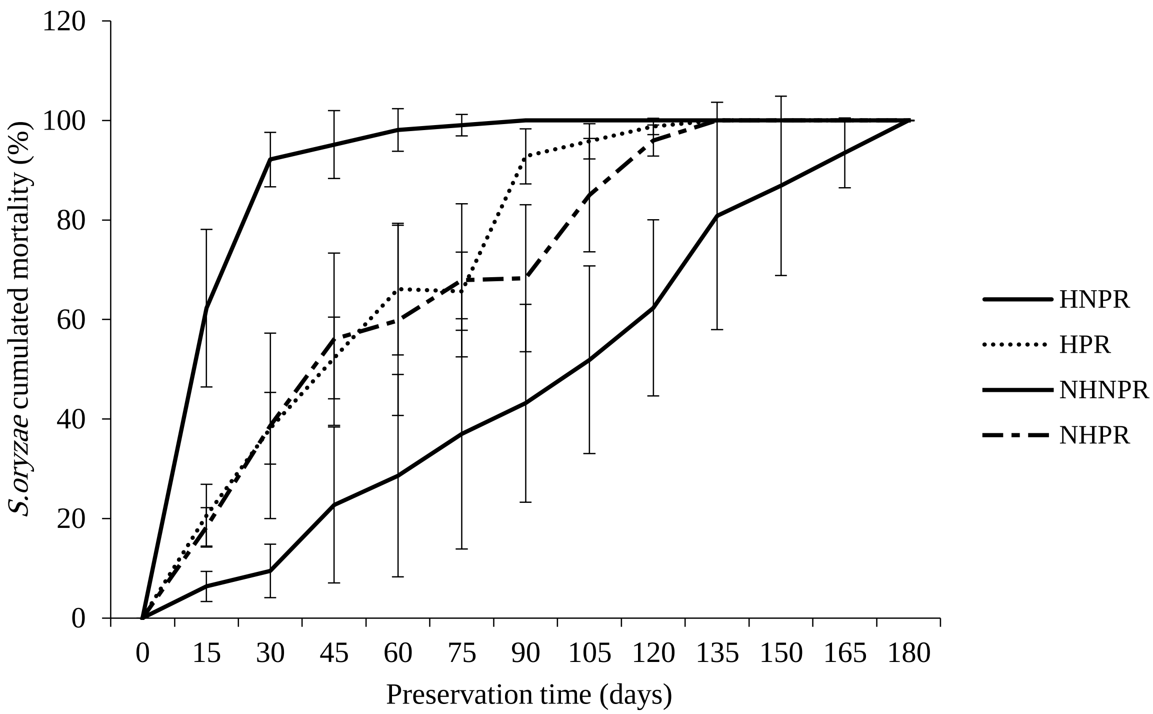

Figure 2: *S.oryzae* cumulated mortality in different rice treatment

HPR and NHPR have similar effects on the various population parameters measured on *S. oryzae* and are somehow intermediate between NHNPR and HNPR. Indeed, both types of parboiled rice allowed for a slight increase in the number of *S. oryzae* living individuals and biomass after 45 days of trial, showing that reproduction was successful. In addition, *S. oryzae* mortality rates on these two types of parboiled rice are significantly lower than those observed in the NHNPR. These results suggest that these two types of parboiled rice have physicochemical characteristics slightly better than those of NHNPR, but not as good as HNPR, and not enough to maintain the population over a long period, as indicated by the absence of living individuals after 180 days.

3.4. Effect of rice treatment on mortality inside the sex

While both treatment (F = 35.54; df= 3; P < 0.0001) and time (F = 15.4; df= 11; P < 0.0001) had highly significant effect on mortality rate, sex did not show any (F = 1.33; df= 1; P > 0.25). The interaction between rice treatment and sex (F = 5.35; df= 3; P = 0.004), or between treatment and time (F = 2.81; df= 33; P < 0.0001), as well as time and sex (F = 2.81; df= 11; P = 0.001) were significant. Sex did not have the same effect on all treatment: female mortality was higher than males on HPR only after 60 days (P < 0.0001) and 90 days (P < 0.0001), but was lower than male after 75 days (P < 0.0001).

Parboiling and husking the rice thus have different impact on the preference by *S. oryzae*. Steaming softens and causes cracking of the rice ball (protective covering of the rice grain) (Bienvenido, 1994) while husking the rice completely gets rid of this envelope in parboiled rice only, making the grain of rice attainable to *S. oryzae* in both cases. The parboiled rice bran covering the grain, which is just below the ball and not eliminated by husking, contains a relatively important fraction of proteins and lipids (Padua and Juliano 1974). The accessibility to these nutrients in parboiled rice, husked or not, could therefore explain the relatively low mortality rates and increase in biomass after 45 days of *S. oryzae* on HPR and NHPR of rice compared to NHNPR. In addition, the emergence of adults from a new generation shows that larvae on the two types of parboiled rice disposed of sufficient food resources to accomplish their full development within the rice grains.

However, the HPR and NHPR were not as suitable for *S. oryzae* populations as HNPR. Steaming rice causes an inward diffusion of many nutrients (proteins, lipids and carbohydrates), minerals and vitamins (water soluble vitamins), concentrated on the periphery of the grain (Padua and Juliano, 1974; Cruz, et al., 1988; Bienvenido, 1994). In addition, soaking and steam heating cause gelatinization of starch granules witch swell and fill all the gaps in the intercellular spaces inside the rice grain and hardening of the endosperm, making the compact texture of the grain homogeneous, glassy and hard (Gariboldi, 1984). These characteristics of parboiled rice are obstacles to *S. oryzae* adult survival and larval development, as they only have access to small fractions of proteins and lipids present in the bran. Moreover, there are not enough empty spaces inside the grain of parboiled rice, preventing proper development of *S. oryzae* larvae whose cycle takes place entirely inside the grain. Finally, females' oviposition behavior could be affected by this physical characteristic of parboiled rice grain, because they will take longer to penetrate the hardened pericarp of the grain.

In species such as *S. oryzae*, the population survival and growth depends on the physicochemical characteristics of the resource (Fitt, 1984; Doumbia, 1998; Doumbia et al., 1998; Hemptinne et al., 2000). Females should thus choose the best resource for the larvae, and they effectively lay more on large grain sizes that offer a higher survival rate to larvae compared to small grain sizes (Campbell, 2002). However, in our study, females could not select their oviposition substrate, and the population was thereafter affected by the imposed resource.

This study can provide better control methods by bringing information on the impact of rice treatment on *S. oryzae*. It would be more preferable to store the paddy in boots non-shelled or carry out rice steaming, if the shelling is desired, with a view to a long conservation in rural areas. However, we must acknowledge that there is a trade-off between the best preservation method against *S. oryzae* and the eating habits, as parboiled rice is less appreciated by consumers.

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