Forecasting the Necessity of Grain Fumigation during Storage

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Abstract

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According to the simulation models composed for the population growth and feeding damage of the insects: *Sitophilus oryzae* (L.), *Sitophilus granarius* (L.) and *Rhizopertha dominica* (F.) the populations densities have been determined at which the grain fumigation costs at using phosphorus hydrogen preparations equal the damage values caused by insects. The necessity of fumigation can be forecasted, according to the population growth time up to these limits. For this purpose, simulation models at temperatures of 21, 24, 27, and 30°C have been used. The products of time and temperature should be calculated at different temperatures and compared according to the simulation results and forecast temperature values during grain storage in particular granary. The action thresholds have been determined according to the models, at which fumigation should be carried out so that no economical losses or quality deterioration of grain be admitted. The results forecast have also been confirmed by freshly harvested wheat storage in a flat storehouse and a metal silo bin. It has been established that grain fumigation can be avoided if grain is stored in flat storehouses and cooled down by ventilation.

Keywords: insect; stored grain; damage (loss); simulation model; action threshold; fumigation

Pest infestation has been one of the main problems, which arise during grain storage. In such cases, where by preventive measures no limitation or inhibition of the insect population growth can be achieved, the pest should be destroyed by fumigation. On the other hand, based on ecological and economical considerations, fumigation could be undesirable. Besides, its limitation is necessary also because of insects increased resistance towards fumigants. This has imposed the necessity of fumigation forecasting, for which, however, there is no efficient methodology exists.

It is considered that, for the prevention of economical losses or quality deterioration of grain and grain products, fumigation should be done when the infestation rate has reached the action threshold, still known as the economical threshold (Hagstrum & Flinn 1992; Vela-Coiffier *et al.* 1997).

The action threshold, which has been accepted in the USA, means, two or more live insects in a sample of 1 kg. For the acceptation of these values no well-grounded data exist. The above-mentioned grain is designated as infected and because of that its market price sometime decreases (Anonymous 1994). Besides that, no well-grounded data for this concept have been accepted in Bulgaria, namely that grain is considered to be infected when its infestation rate is higher than 5 insects per kg.

From the economical point of view, fumigation is considered to be imperative when it is expected that during the grain storage the infestation rate will increase and will reach the levels at which the permitted damage value or the grain price decrease rate will be equal to the costs. The measures are also necessary at the expected grain quality deterioration caused by the development of insects to the degree not allowing its utilisation for the human consumption (Antonovich 1987; Hagstrum & Flinn 1992; Flinn *et al.* 2007). This applies when decision on fumigation should be made taking into account the grain temperature variation and insect population. The realisation term should be known as well.

The purpose of this investigation is to determine the action threshold and to forecast the necessity of fumigation with phosphorus hydrogen preparations on the basis of the expected losses arising from insects feeding under particular storage conditions.

MATERIALS AND METHODS

In order to forecast the growth rates of the most harmful and widely spread internally feeding insects populations – the rice weevil *Sitophilus oryzae* (L.), the granary weevil *Sitophilus granarius* (L.), and also the minor grain borer *Rhizopertha dominica* (F.), we have used simulation models developed by us (Kuzmanov & Dimitrov 2007) according to the way described by Hagstrum and Throne (1989) and Hagstrum and Flinn (1990). The data required for the duration of the insect development at separate stages and various temperatures have been taken from the investigations done in Bulgaria.

The simulation was made at temperatures of 21, 24, 27, and 30°C and the moisture content at which the wheat is most often stored 12–13%. The validity of the simulation models at a temperature of 27 ± 0.64°C was determined at wheat storage in a metal silo bin with a capacity of 2500 t, using the analysis of linear regression dependence between the infestation rate values obtained during periodical measurements, and those determined by means of the model. The real density values (y) calculated according to the regression equation ($y = ax + b$) and those predicted by using the simulation model (x) reflect 82%, 92%, and 80% of the population density variation of the pests *S. oryzae, R. dominica,* and *S. granarius*, respectively (Table 1). In all cases investigated, the coefficients a were indiscernible from 1 and the coefficients b from 0, which was an index for the good coincidence of the pests population growth rate forecast by the model and that determined in practice.

In order to forecast the damage increase, we obtained additionally the simulation models with modules reporting the insect feeding damage, using for this purpose the data for the everyday damage caused by the adult insect as well as the total ones caused by one larva during its development (Ilcheva *et al.* 1996; Obretenchev *et al.* 1996).

For the confirmation of the forecast necessity of fumigation, we have used the data for the temperature and infestation rate variations of freshly harvested wheat stored in a metal silo bin and in a flat storehouse, with capacities of 2500 t and 3000 t, respectively. The initial temperature of wheat was 31–32°C, and its average moisture content 12.8%. The temperature of two layers of the grain bulk at a distance of 0.5 m and 2 m from the surface was periodically measured every 14 days using an electronic thermal probe with the accuracy of 0.2°C. The grain temperature in the silo bin was measured in 9 points (1 in the center and 4 points each at a distance of 0.7 and 4.5 m from the wall), and in the flat storehouse – in 15 points (3 points each along the ridge, two slopes, and by the walls). The infestation rate was determined every 15 days, using the method of taking samples by means of a cylindrical probe trier (1 m in length and 0.5 kg in capacity) from 5 points in the silo bin (1 in the centre and 4 along the semi-radius) and 9 in the flat storehouse (3 on the ridge of the embankment, and the remaining ones between the ridge and the walls). The insects were separated by sieving the samples and their number was calculated per 1 kg.

Table 1. Parameters for regression of measured (y) against predicted (x) densities of *S. oryzae, S. granarius* and *R. dominica* populations

Insect	n	Slope a ± SD	t_a (H_0: a = 1)	P_a	Intersept b ± SD	t_b (H_0: b = 0)	P_b	R^2
S. oryzae	5	1.13 ± 0.49	1.49	0.15	–0.68 ± 2.25	0.30	0.76	0.82
S. granarius	7	1.35 ± 0.41	0.85	0.43	0.38 ± 0.20	1.9	0.12	0.80
R. dominica	6	1.28 ± 0.15	0.97	0.37	0.25 ± 0.90	0.28	0.79	0.92

From the beginning of storage, the wheat has been cooled down by atmospheric air ventilation during the night (22–6 h).

RESULTS AND DISCUSSION

The increase of the extent damages caused by the feeding of a couple of insects and their generation upon wheat stored at 27°C is presented in Figure 1. The results have shown that at the beginning the damages grew insignificantly up to 0.5 kg/t. Such damage has no practical significance because the least error possible at measuring the grain weight in practice is 0.05%. After that, damage started to increase quickly, which imposed undertaking the pest control so that significant damage should be avoided. Because of that, we accepted that at this moment the infestation rate had reached the action threshold. From the simulation results of the insect population growth in 1 t of wheat (Figure 2) we determined that for the time required to reach the action threshold, the infestation density of *S. oryzae* and *S. granarius* had increased up to 8.5 and that of *R. dominica* – up to 10 insects per kg.

According to the damage weight caused by the larvae and the elderly insects, the insects were arranged in the following order: *R. dominica*, *S. granarius,* and *S. oryzae*. However, as far as the total damage and time needed to reach the action threshold were concerned, the three species were been arranged in a reverse order, which was explained by the different rate of the population growth. That is why, as regards the damage caused at the grain temperature of 27°C, *S. oryzae* is the greatest danger for the stored grain.

The fumigation at the action threshold has been economically justified if is expected that, before the grain realisation, the damage value during its storage at the respective market the price will be equalised to the costs. For example, the fumigation costs of 1 t grain by using the only nowadays used phosphorus hydrogen preparations amount to the average of $ 0.75 (according to the prices in Bulgaria). Of this, 60% is used for the preparation of the dose of 5 g PH_3/t, 30% for the labour costs (levelling the grain bulk, manipulations, periodical measurements of PH_3 in the grain mass, ventilation, determination of the fumigation effect by taking samples and subsequent determination of he death rate), 5% for the transport costs, and 5% for consumables costs. These costs are equivalent to the cost of 5 kg of wheat at an average price of $150/t.

According to the simulation results, the damage amounting to 5 kg/t were obtained from the generation of a couple of insects for the time during which the population density of *S. oryzae* and *S. granarius* had reached 68, and *R. dominica* – 98 insects per kg (Figure 2).

On the other hand, fumigation is also necessary if it is expected that during the grain storage the number of insect-damaged kernels will reach the

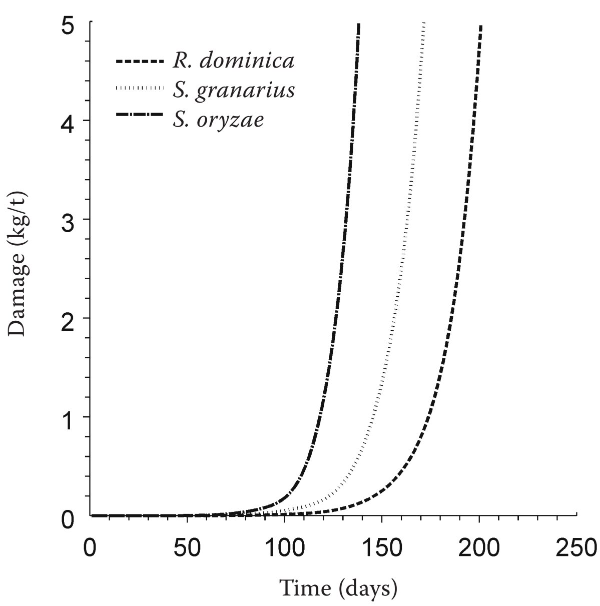

Figure 1. Damage increase caused by the feeding of a couple of insects and their generation at a temperature of 27°C

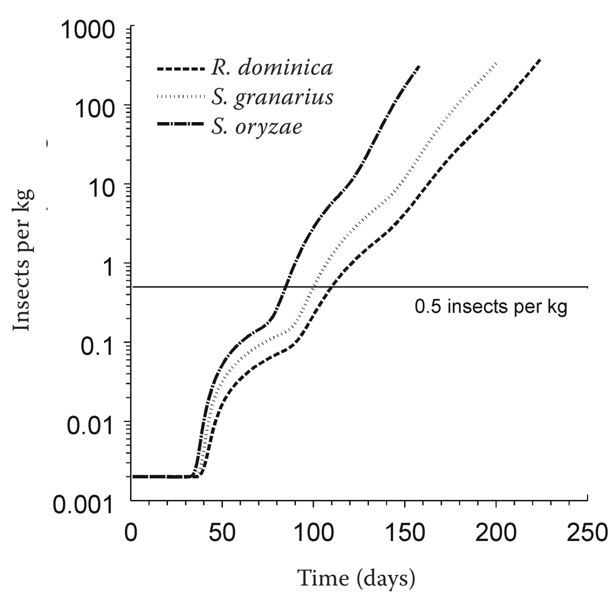

Figure 2. Population growth of a couple of insects at a temperature of 27°C

admissible value of 32/100 g (Flinn *et al.* 2007), which is equivalent to the population density of 320 insects per kg (Hagstrum & Flinn 1992). At such a density, however, the damage value will be considerably higher than the fumigation costs.

Besides that, fumigation is justified as well in the cases when it is expected that the infestation rate will also reach the toxic threshold – 90 insects per kg (Antonovich 1987).

In the case of the infected grain price decreasing by more than 0.5%, which may rarely happen, this processing will also be required.

The comparison of the above data has given us grounds to accept that the values of 68 insects per kg for *S. oryzae* and *S. granarius* and 90 insects per kg for *R. dominica* appear as economical limitations of the infestation rate, at whose presumed attainment the grain should be fumigated at the action threshold. From the economical point of view, fumigation is justified when the grain realisation or processing can be done after reaching the limitations.

If wheat price or fumigation costs change, the respective limitations will be determined in the same way.

In grain storage, to forecast the time necessary for reaching these limitations we will need the initial infestation rate value, obtained by stored grain monitoring. If we accept as such 0.5 insects per kg – the least infestation rate, which can be detected by the method of samples taking, we establish as seen in Figure 2, that the limitations of 68 insects per kg for *S. oryzae* and *S. granarius* and 90 insects per kg for *R. dominica* have been reached after 52, 69 and 92 days, respectively, while the action threshold – after 27, 32, and 53 days, provides enough time for organising and carrying out fumigation of stored grain, when needed.

At temperatures different from 27°C, in order to determine the time necessary for reaching these limitations, we analogically used the simulation results for the insect population growth at temperatures of 21, 24, and 30°C (Table 2). The data show that the equalisation of damage and fumigation costs were reached most quickly in the case of infestation with *S. oryzae* and after that – with *S. granarius* and *R. dominica*. Fumigation was justified at temperatures above 21°C when infestation occurred with *S. oryzae,* and above 24°C – with the other two species. This has been explained by the thermophilic ability of *R. dominica* and the smaller population growth rate of *S. granarius* at lower temperatures.

Usually, in grain storage, its temperature varies. In such cases to forecast the necessity of fumigation, we proposed to use the products of time multiplied by temperatures ($t \times T$) – see Table 2. With the values obtained, we compared the product of time for the grain storage after we detected the infestation rate of 0.5 insects per kg and the forecast grain temperatures for the next 3 months, which can be calculated according to the formula:

$$t \times T = \sum_{i=1}^{n}(t_i \times T_i)$$

$$t_i \times T_i = \frac{T_i + T_{i-1}}{2}\Delta t_i$$

where:

Δt_i – time between two forecast temperature values (days) (Δt_i = 15–20 days)

T_i, T_{i-1} – forecast temperatures at the beginning and at the end of the period (°C)

When $t \times T$ for the particular granary is equal or greater than that calculated after the simulation data for the respective times, the damage value has reached or surpassed the fumigation costs. In order to facilitate the comparison, the results presented graphically. As an example in Figure 3, besides the values of $t \times T$ calculated according to

Table 2. Times for reaching the economical limitations after infestation rate of 0.5 insects/kg at various temperatures (days)

Insect	Temperature (°C)			
	21	24	27	30
S. oryzae	84	64	52	49
S. granarius	–	98	72	69
R. dominica	–	138	91	72

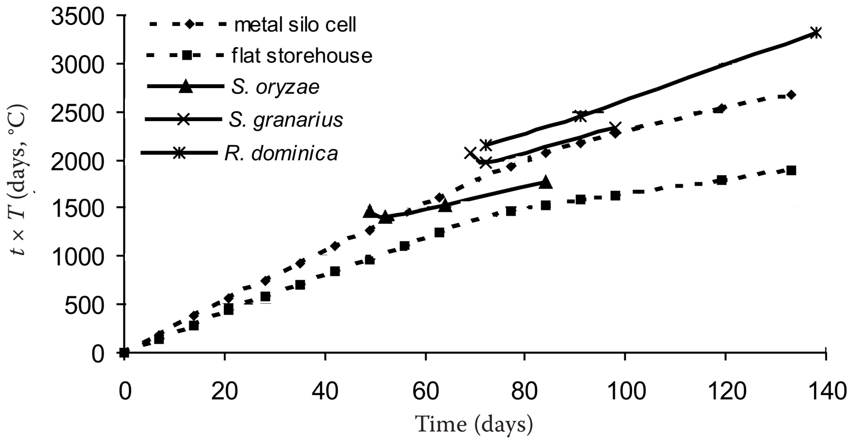

Figure 3. Simulation and real values of "$t \times T$" of wheat stored in a metal silo bin and in a flat storehouse after infestation rate of 0.5 insects per kg

the simulation results (Table 2), we also showed the real values of wheat storage in a metal silo bin and in a flat storehouse after detecting the infestation rate of 0.5 insects per kg at the beginning of September, according to the formula. Characteristic for the grain temperature was a decrease as a result of ventilation after filling the granaries, having fallen after about 20 days from 31–32°C to 26°C. After this period, the temperature in the flat storehouse continued to decrease at about the same rate, while in the silo bin it remained within the limits of 27–28°C for about 50 days more. The reasons for the slower grain cooling in the silo bin was the less specific airflow rate during ventilation (10 m^3/h.t.) and the more significant airflow heating in the fan (4°C). Because of that, it is only the silo bin line which crosses that of the simulation for *S. oryzae* after about 58 days – the moment of equalisation between the damage

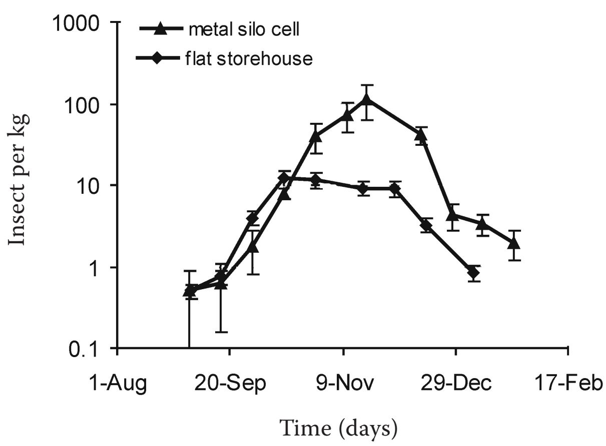

Figure 4. Change of infestation (± SD) by *S. oryzae* in storage of freshly harvested wheat in a metal silo bin and in a flat storehouse

rate and fumigation costs. That is why, in the case of a later grain realisation, fumigation should be done after reaching the action threshold. The flat storehouse line does not cross the lines for the three insects, because of which grain fumigation is not economically justified.

In order to compare the forecasting results with the real ones, Figure 4 shows the infestation rate variation of *S. oryzae* in stored wheat in both granaries. Because of the higher grain temperature in the silo bin population the density reached the economical limitation of 68 insects per kg after 67 days (by about 10 days later as compared with the time forecast according to Figure 3). In order to avoid the damage costs admitted, the grain should have been fumigated during the first half of October when the action threshold of 8.5 insects per kg was reached. Because fumigation was not carried out, the infestation rate reached the toxic threshold – 90 insects per kg.

When grain was stored in the flat storehouse, the maximum infestation rate was 10 times lower than in the silo bin. It was not possible to reach the economical limitation of 68 insects per kg, because of which stored grain fumigation was not imperative.

CONCLUSIONS

At storage of freshly harvested grain in flat storehouses and its cooling down by atmospheric air ventilation, fumigation is economically justified because the insects damage value is considerably smaller than the costs which would arise. Fumigation is imperative when the storage continues for more than 4 months in metal silo bins with a great capacity when infestation rate of 0.5 insects per kg of *S. oryzae* is detected at the beginning of September.

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