Journal of Stored Products Research 56 (2014) 67–80

Contents lists available at SciVerse ScienceDirect

Journal of Stored Products Research

journal homepage: www.elsevier.com/locate/jspr

# How many kilograms of grain per sample unit is big enough? Part II – Simulation of sampling from grain mass with different insect densities and distribution patterns

Fuji Jian [a], Digvir S. Jayas [a,*], Noel D.G. White [b]

[a] Department of Biosystems Engineering, University of Manitoba, Winnipeg, MB, Canada R3T 5V6
[b] Cereal Research Centre, Agriculture and Agri-Food Canada, 195 Dafoe Road, Winnipeg, MB, Canada R3T 2M9

ARTICLE INFO

Article history:
Accepted 30 May 2013

Keywords:
Sampling
Insect detection
Density estimation
Insect distribution
Simulation

ABSTRACT

To find representative sampling sizes and units, adult numbers and distributions inside 2700 kg wheat were generated by a computer program. The generated densities of insects with uniform or clumped distributions inside the grain mass were: 0.1, 0.5, 1.0, 2.5, 5.0, and 10.0 adults/kg of grain (A/kg). The grain mass was artificially sampled by the computer program using different combinations of sampling sizes and units. The simulated sampling sizes (number of samples in one sampling set) were: 5, 10, 20, 40, 60, and 100. The simulated sampling units were: 0.5, 1.0, 2.5, 5.0, 7.5, 10.0, and 13.5 kg. When 100 sampling size and a 13.5 kg sampling unit were applied, 50% of the total grain was sampled. Simulation results revealed that more samples were required to detect clumped distributed insects than uniformly distributed insects. Both sample size and unit should be increased with the decrease of insect densities. When insect density was 0.1 A/kg, using 2.5–7.5 kg sampling units would sample less grain mass than that using other sample units to detect insects. To estimate insect density with certain accuracy, sampling size and unit should be properly selected. Using sampling method to estimate insect densities with less than 60% of percent relative variance might not be practical when insect densities were less than 1.0 A/kg. Insect distribution could be incorrectly characterized when sampling size and unit were not chosen correctly. When insect densities were ≤0.5 A/kg, ≥100 sampling sizes with ≥10.0 kg sampling unit were required to accurately characterize insect distribution.



## 1. Introduction

Insect contamination and loss caused by insect infestation represents a serious and continuing problem for the grain industry. To detect insects and estimate their density inside a stored grain bulk, the conventional and common method is to sample the grain. The amount of grain in each sampling unit is usually around 0.5 kg of grain (manual sampling) or 2.75 kg of grain (mechanical sampling) (Jian et al., 2011a). The captured insects inside the samples are used to estimate insect densities or distribution patterns or both.

There are several studies using this method to estimate insect density and develop sampling plans. Hagstrum et al. (1985) developed a sampling plan and suggested that insect densities can be estimated on the basis of presence or absence of insects inside the samples. However, they found that too many samples are required at low insect densities (roughly 24.5 t in 82–122 t bins). At high insect densities, the fraction of samples with insect increases progressively more slowly, resulting in poor resolution above one insect per 0.5 kg of wheat. A sequential sampling plan and optimum sample size of the probe sampling for *Cryptolestes ferrugineus* (Stephens) in infested farm-stored bulks was developed (Subramanyam and Harein, 1990; Subramanyam et al., 1997). This sequence sampling plan can estimate higher than the economic threshold density (1 insect/0.5 kg sample unit) of *C. ferrugineus*. Hagstrum et al. (1985) concluded that one probe sample did not predict very well the insect density in another grain sample taken at a distance of 30 cm. These conclusions and recommendations are consistent with the reports that this sampling method is inaccurate when detecting population densities at ≤4 insects per kilogram of grain (Wright and Mills, 1983; White and Loschiavo, 1986; Wilkin and Fleurat-Lessard, 1990). In Part I of this article (Jian et al., 2014), we found 0.5 kg samples with 5

* Corresponding author.
E-mail address: Digvir.Jayas@umanitoba.ca (D.S. Jayas).

0022-474X/$ – see front matter Crown Copyright © 2013 Published by Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.jspr.2013.05.006

sample size could not detect the existence of adults, estimate insect densities, and characterize insect distributions when insect density was ≤1.0 adults per kg wheat. Therefore, the reliability and accuracy of this method is questionable.

When this sampling method is used to estimate densities and distribution patterns of insects, the real insect densities and distributions inside the grain are not known. Without this information of insect numbers and distributions, researchers or samplers usually use statistical tools to estimate the sampling accuracy with an assumption that the sample size and unit could provide a representative statistical population that accurately reflects the entire population inside the bins. This assumption might be true when the sample size and unit are big enough (Davis, 1994). Jian et al. (2011a) recommended that at least 7 kg per sample unit must be collected for insect detection (especially when insect densities ≤ 0.1 A/kg) and the optimum number of samples with 15 kg grain per unit should be >24 for a fixed precision of 0.35 when insect densities < 0.1 A/kg. This means that more than 5.5 t of grain inside a 50 t grain bin should be examined to detect the existence of the insects inside the grain. Considering the work involved to remove the 5.5 t of grain, separate insects from the grain, and identify the separated insects, it might be a challenge to use a big enough sample size with large enough sample units. With a small sample unit and size, this assumption could be wrong or at least could not be verified if the insect distribution or the real number of insects inside grain bulk is not known (Kuno, 1991; Pedigo and Buntin, 1993). If the sample size and unit do not provide a representative statistical population, the sampling method can affect the observed spatial pattern and the estimation of insect density (Davis, 1994). The dilemma is that distributions of insects cannot be characterized and insect number cannot be estimated before a representative statistical population is provided. Therefore, the critical question is: how many kilograms of grain in each sample unit is big enough and can be counted as a representative sample? How many samples is a big enough sample size?

Statistical theories might answer these questions only when insect distributions follow statistical distributions such as binomial or uniform, random or Poisson, and negative binomial. Insect populations might follow three distribution patterns (Southwood, 1978): 1) binomial or uniform; 2) random or Poisson; or 3) negative binomial, aggregated or clumped. The count frequency of stored-product insects could not be fitted to either of these distributions except the clumped distribution (Jian et al., 2011a, 2012a,b,c). For example, the count frequency of the adults of *C. ferrugineus* fitted the model of negative binomial, positive binomial, and Poisson distribution only 22.2%, 13.9%, and 13.9% of the time, respectively. Stored-product insects have uniform or clumped distribution and the degree of aggregation is influenced by biological and physical factors such as insect density, temperature and grain moisture content (Athanassiou et al., 2003; Jian et al., 2011a, 2012a,b,c). Therefore, answering these questions using statistical calculation might be difficult due to the complexity of the insect distribution. Also, it is impossible to interpret degree of aggregation because the ratio of variance and mean of insect densities has no upper limit. Experimental testing might answer some of these questions. However, experimental testing might require more than three full-size bins, examining all the grain inside the bins; and repeating these tests for several years for only one species. If different patterns of insect distribution are considered, more experiments need to be conducted. Considering the work involved in the separation of insects from grain which might be removed during the examination period, conducting such experiments would be a challenge.

Computer simulation can generate different insect distributions with different insect densities. The insect number at each location can be generated by a computer program, thus, the true distributions are known before sampling is conducted. Such a procedure allows estimation of the accuracy of the true insect density because statistical error is not involved in determining the true density. This simulation can find the representative sample size and unit by checking whether the insect density estimated and distribution pattern characterized by the samples are the same as that generated by the computer program. Different amounts of grain per sample unit associated with different sample sizes can be examined by using simulation. Different distributions and insect densities can be tested and the effects of individual factors can be isolated in simulation by changing only one factor at a time. This simulation also answers whether this sampling method is practical for grain managers.

Grain storage practice requires high accuracy sampling methods especially for high value products or for long term storage. The data collected by using a sampling method should be correctly interpreted. There are no studies to show the accuracy (precision) of different combinations of sampling sizes and units, and the representative sample sizes and units for the characterization of insect distributions. Considering manual sampling method is commonly used and its results might be misleading in some situations, its accuracy and reliability on the detection of insects, estimation of insect densities, and characterisation of insect distribution should be thoroughly evaluated.

The objectives of this study were to: 1) determine the precision of the sampling method associated with different combinations of sampling sizes and sampling units; 2) find the representative sample size and unit under different insect distribution patterns and insect densities; and 3) study the feasibility of manual sampling method in the detection of insects, estimation of insect densities, and characterization of insect distributions. The simulation results were analyzed in correlation with the data collected in Part I (Jian et al., 2014).

## 2. Simulation methods

### 2.1. Assumptions

1. Total mass of a grain bulk was 2700 kg and the grain was stored inside a bin which could be of any shape. The bulk grain was discretized into 200 primary-cubes and each primary-cube was further sub-divided into 27 sub-cubes (Fig. 1). The grain inside a primary-cube was 13.5 kg and inside a sub-cube was 0.5 kg. Bulk density of the grain was the same throughout the grain mass.
2. The overall insect density inside the total grain mass (200 primary-cubes) was 0.1, 0.5, 1.0, 2.5, 5.0, or 10.0 adults/kg grain (referred to as A/kg). Maximum and minimum insect numbers inside each primary-cube or sub-cube at different insect densities were assumed and these assumed numbers were based on the data collected in Jian et al. (2014) and in our earlier works (Jian et al., 2011a,b, 2012a,b,c).
3. The insect distribution patterns inside the primary-cubes were uniform or clumped. Inside a given primary-cube (regardless of the insect distribution among the primary-cubes), insects randomly distributed inside the 27 sub-cubes.
4. Each primary-cube had the same chance of being randomly sampled.

### 2.2. Simulation procedures

#### 2.2.1. Generation of insect distributions

Uniform distribution of the insects was created by randomly choosing primary-cubes at the beginning of the simulation (Fig. 2).