Phytosanitary procedures
Procédures phytosanitaires

Sampling of consignments for visual phytosanitary inspection

Specific scope

This standard describes the statistical basis of sampling for visual phytosanitary inspection of consignments.

Specific scope

First approved in 2005-09.

Introduction

Inspection of consignments of plant and plant products moving in international trade is an essential tool for management of pest risks and is the most frequently used phytosanitary procedure worldwide, for both import and export. Article VI of the New Revised Text of the IPPC states that each contracting party shall make arrangement for phytosanitary certification, with the objective of ensuring that exported plants and plant products and other regulated articles are in conformity with the certifying statements of the phytosanitary certificate. The certifying statements in the models set out in the annex of the New Revised Text of the IPPC are:

For the phytosanitary certificate '*This is to certify that the plants, plant products or other regulated articles described herein have been inspected and/or tested according to appropriate official procedures and are considered to be free from the quarantine pests specified by the importing contracting party and to conform with the current phytosanitary requirements of the importing contracting party, including those for regulated non-quarantine pests*'.

For the phytosanitary certificate for re-export: '*This is to certify that the plants, plant products or other regulated articles … are considered to conform with the current phytosanitary requirements of the importing contracting party, and that during storage … the consignment has not been subjected to the risk of infestation or infection*'.

From these statements it can be concluded that it is the responsibility of the exporting country (where appropriate the country of re-export) to verify that the plants, plant products or other regulated articles comply with the phytosanitary requirements of the importing country before issuance of a phytosanitary certificate (see also *ISPM* no. 7 Export Certification System, 1997). Import inspection is then a control procedure performed by the importing country to verify the compliance of the consignment with the appropriate phytosanitary requirements.

An inspection may lead to actions such as:

- refusal to issue a Phytosanitary Certificate for a consignment (or part of a consignment) intended to be exported,
- refusal of entry, detention, treatment, destruction or removal from the territory of the importing country for a consignment (or part of a consignment) at import.

Thus it is important that the inspection methodology (including the sampling procedures) used by NPPOs should be documented and transparent.

Phytosanitary inspection

In ISPM no. 5 Glossary of Phytosanitary terms, inspection is defined as '*Official visual examination of plants, plant products or other regulated articles to determine if pests are present and/or to determine compliance with phytosanitary regulation*'. Pre-export inspection as well as import inspection often refers to consignments. As defined in ISPM no. 5 Glossary of Phytosanitary terms, a consignment is '*a quantity of plants, plant products and/or other articles being moved from one country to another and covered, when required, by a single phytosanitary certificate (a consignment may be composed of one or more commodities or lots)*'. A lot is defined as '*a number of units of a single commodity, identifiable by its homogeneity of composition, origin, etc., forming part of a consignment*'. Where consignments are composed of lots, the phytosanitary inspection should be performed on the basis of identifiable lots, not consignments, and the criteria used to distinguish lots should be consistent for similar consignments. Phytosanitary inspection of imported consignments may be carried out at

reduced frequency if experience gained from earlier introductions of plants, plant products or other articles of the same origin indicates that the articles in the consignment or lot are likely to comply with the phytosanitary import requirements of the country concerned.

Visual examination is a common practice for the detection of pests that are visually identifiable, or whose signs or symptoms are easily distinguishable. It is also a common procedure for verification of compliance with specific phytosanitary requirements (e.g. freedom from soil, packaging requirements, dormancy...). It is often not feasible to inspect every item in a consignment, so phytosanitary inspection is mainly based on sampling. Samples are used to draw inferences on the phytosanitary status of the whole consignment.

Sampling of consignments or lots

Sampling for phytosanitary inspection of consignments

Sampling for phytosanitary inspection of consignments or lots is a form of 'discovery sampling'. Samples are taken from a finite population (the consignment or lot) without replacement of the units selected[1]. The consignment or lot is rejected if one or more defects are detected in the sample. Defects in the case of a phytosanitary inspection means:

- presence of quarantine pests
- presence of regulated non-quarantine pests above a prescribed tolerance level of infestation in the consignment
- presence of signs or symptoms of regulated pests indicating non-compliance with phytosanitary requirements
- evidence of non-compliance with phytosanitary requirements (such as soil on roots when soil freedom is required).

Rejection in the case of a phytosanitary inspection means that the consignment (or lot) from which the sample has been taken may be submitted to phytosanitary action.

Information provided by sampling

Sampling can never prove that a pest is truly absent. Inspection based on sampling can only demonstrate that the frequency of infestation is below a specified level or within a specified range, with a known level of confidence. Sampling to identify defects is common practice in industry and statistical tools exist to determine the size of samples.

Elements to be considered in determining sample size

Lot size

The lot size is a variable that cannot be controlled by the NPPO.

[1]Sampling without replacement does not mean that the selected item cannot be returned to consignments (except for destructive sampling), it just means that the inspector should not return it before selecting the next items.

Level of confidence

This confidence level corresponds to the percentage of success in discovering a defect. Sampling plans may be specified in relevant phytosanitary procedures for consignment inspection. Each sampling plan has a level of confidence which should be set in advance (commonly 99% for plants for planting and between 80 and 95% for fruits and vegetables or cut flowers; guidance is provided in specific commodity procedures). Large sample sizes are required to achieve a high level of confidence. These are often difficult to manage.

Infestation level in the consignment

The infestation level is defined as the percentage or proportion of infested units in the consignment or lot. The infestation level of the consignment is not likely to be known (furthermore, it is expected to be zero in the case of quarantine pests). The level of infestation to be detected should be fixed by the NPPO so that a sampling regime can be established. Commonly used levels of infection to be detected are between 0.1% and 10% depending mainly on the commodity and its intended use. Lower values are fixed for plants for planting (usually less than 1%), than for fruits and vegetables (between 5 and 10%).

Distribution of the pest in the consignment or lot

There is usually no information on the distribution of the pest in a consignment, though it may be influenced by the biology of the pest concerned, which should be taken into account as far as possible in deciding on the sampling methods to be used. In the case of large consignments or lots, it can be considered that the commodity has been sufficiently mixed to be considered homogeneous. As a consequence, the hypothesis that the distribution of the pest in the consignment or lot is homogeneous can be made and binomial-based sampling can be used. When the distribution of the pest is presumed to be aggregated, beta binomial-based sampling is preferable.

Determination of the sample size

Inspection of a fixed proportion of the consignment or lot is not always the most effective sampling method (in particular, for small consignment or lots, see Table 1). Discovery sampling follows statistical laws that depend on the size of the inspected consignment or lot and the potential distribution of the pest in the consignment or lot.

Homogeneous distribution of the pest in the consignment or lot

In the case of large consignments or lots, and when the sample size is below 5% of the consignment or lot, sampling is based on the binomial distribution (see the Appendix). The sample size is independent of the consignment or lot size, as it is considered

Table 1 Sampling strategies to examine commodities assuming 10% of the boxes have an infested commodity unit (from RC Venette *et al*., 2002)

	Hypergeometric-based sampling		Fixed sampling rate (2%)	
Boxes on truck	Boxes to inspect	Probability of detecting infested cargo	Boxes to inspect	Probability of detecting infested cargo
10	10	1	1	0.100
50	22	0.954	1	0.100
100	25	0.952	2	0.190
200	27	0.953	4	0.344
300	28	0.955	6	0.469
400	28	0.953	8	0.570
500	28	0.952	10	0.651
1000	28	0.955	20	0.878
1500	29	0.954	30	0.958
3000	29	0.954	60	0.998

Table 2(a) General sampling tables: sample size for visual inspection (homogeneous distribution of the pest in the consignment or lot)

Number of units in consignment	P = 80% (confidence level) % level of infestation					P = 90% (confidence level) % level of infestation				
	5	2	1	0.5	0.1	5	2	1	0.5	0.1
100	27	56	80	–	–	37	69	90	–	–
200	30	66	111	160	–	41	87	137	180	–
300	30	70	125	240*	–	42	95	161	270*	–
400	31	73	133	221	–	43	100	175	273	–
500	31	74	138	277*	–	43	102	184	342*	–
600	31	75	141	249	–	44	104	191	321	–
700	31	76	144	291*	–	44	106	196	375*	–
800	31	76	146	265	–	44	107	200	349	–
900	31	77	147	298*	–	44	108	203	394*	–
1 000	31	77	148	275	800	44	108	205	369	900
2 000	32	79	154	297	1106	45	111	217	411	1368
3 000	32	79	156	305	1246	45	112	221	426	1607
4 000	32	79	157	309	1325	45	113	223	434	1750
5 000	32	80	158	311	1376	45	113	224	439	1845
6 000	32	80	159	313	1412	45	113	225	443	1912
7 000	32	80	159	314	1438	45	114	226	445	1962
8 000	32	80	159	315	1458	45	114	226	447	2000
9 000	32	80	159	316	1474	45	114	227	448	2031
10 000	32	80	159	316	1486	45	114	227	449	2056
20 000	32	80	160	319	1546	45	114	228	455	2114
30 000	32	80	160	320	1567	45	114	229	456	2216
40 000	32	80	160	320	1577	45	114	229	457	2237
50 000	32	80	160	321	1584	45	114	229	458	2250
60 000	32	80	160	321	1588	45	114	229	458	2258
70 000	32	80	160	321	1591	45	114	229	458	2265
80 000	32	80	160	321	1593	45	114	229	459	2269
90 000	32	80	160	321	1595	45	114	229	459	2273
100 000	32	80	160	321	1596	45	114	229	459	2276
200 000	32	80	160	321	1603	45	114	229	459	2289

that the global infestation level in large lots remains the same when individual units are sampled.

In the case of small consignments or lots, i.e. when more than 5% of the consignment or lot will be inspected, the infestation level cannot be considered to be constant when individual units are sampled (the probability of finding an infested unit changes with each unit sampled). In such cases the statistical model used to determine the sample size is the hypergeometric distribution (see the Appendix).

The sampling size indicated in Tables 2(a) and 2(b) results from calculations based on the two models described above.

Aggregated spatial distribution of the pest in the consignment or lot

Most pest populations are aggregated or dispersed in the field. Because commodities may be harvested and packed immediately after harvest, the distribution of infested units in a

Table 2(b) General sampling tables: sample size for visual inspection (homogeneous distribution of the pest in the consignment or lot)

Number of units in consignment	P = 95% (confidence level) % level of infestation					P = 99% (confidence level) % level of infestation				
	5	2	1	0.5	0.1	5	2	1	0.5	0.1
25	23	–	–	–	–	25	–	–	–	–
50	35	48	–	–	–	42	50	–	–	–
100	45	78	95	–	–	59	90	99	–	–
200	51	105	155	190	–	73	136	180	198	–
300	54	117	189	285*	–	78	160	235	297*	–
400	55	124	211	311	–	81	174	273	360	–
500	56	129	225	349*	–	83	183	300	421*	–
600	56	132	235	379	–	84	190	321	470	–
700	57	134	243	442*	–	85	195	336	548*	–
800	57	136	249	420	–	85	199	349	546	–
900	57	137	254	474*	–	86	202	359	614*	–
1 000	57	138	258	450	950	86	204	368	601	990
2 000	58	143	277	517	1553	88	216	410	737	1800
3 000	58	145	284	542	1895	89	220	425	792	2353
4 000	58	146	288	556	2108	89	222	433	821	2735
5 000	59	147	290	564	2253	89	223	438	840	3009
6 000	59	147	291	569	2358	90	224	442	852	3214
7 000	59	147	292	573	2437	90	225	444	861	3373
8 000	59	147	293	576	2498	90	225	446	868	3500
9 000	59	148	294	579	2548	90	226	447	874	3604
10 000	59	148	294	581	2588	90	226	448	878	3689
20 000	59	148	296	589	2781	90	227	453	898	4112
30 000	59	148	297	592	2850	90	228	455	905	4268
40 000	59	149	297	594	2885	90	228	456	909	4348
50 000	59	149	298	595	2907	90	228	457	911	4398
60 000	59	149	298	595	2921	90	228	457	912	4431
70 000	59	149	298	596	2932	90	228	457	913	4455
80 000	59	149	298	596	2939	90	228	457	914	4473
90 000	59	149	298	596	2945	90	228	458	915	4488
100 000	59	149	298	596	2950	90	228	458	915	4499
200 000	59	149	298	597	2972	90	228	458	917	4551

Note: Some scenarios presented in the table result in one-half of a unit being infested (for example, 300 units with 0.5% infestation corresponds to 1.5 infested units in the shipment). This is not possible for an individual lot (whole number of units are infested). As a result, values are given for the lower number. The result is that the sampling intensity goes up slightly and may be greater for consignments or lots where the number of infected units is rounded down than for a larger consignment or lot where a larger number of infected units are calculated without rounding (e.g. compare results for 700 and 800 units). It also means that a slightly lower proportion of infested units may be detected than the proportion indicated by the table, or that such infestation is more likely to be detected. These values are marked with an asterisk (*) in the Table.

Some of the scenarios that are presented are not possible (less than one unit infested), and these are marked with a dash (–) in the Table.

consignment or lot may not be homogeneous. Sampling plans can be adjusted to compensate for aggregated spatial distribution. Aggregation of infested units of a commodity will always lower the likelihood of finding an infestation (Fig. 1). In such cases, in theory, Tables 2(a) and 2(b) should not be used. Instead, a calculation of sample size should be performed following the advice in the Appendix. However, this is not easy to undertake in practice and Tables 2(a) and 2(b) can still be followed, keeping in mind that the confidence level of the sampling will be reduced (Fig. 1).

How to sample?

To obtain a statistically valid estimate that the level of infestation in the consignment or lot does not exceed the possible infestation level determined by the NPPO, samples should be taken at random, preferably using random-number tables. Inspections that only target the accessible part of the consignment (tailgate inspection) should be avoided.

For quarantine pests, it is important to maximize the chance of detection by targeting the sample wherever possible at those plants or units which are most likely to be carrying the organism (e.g. by focusing on wet patches of potato bags or on wet sawn wood). This is often based on the experience of the inspector. The inspection procedure, including the collecting and examination of the sample(s), should aim to assure a consistent level of efficacy.

References

Anon (1996) *Harmonized Import Inspection Procedures on Consignments of Third Country Origin*. Commission of the European Union, Brussels (BE).

ICPM (1997) Export certification system. *International Standard for Phytosanitary Measures* no. 7. FAO, Rome (IT).

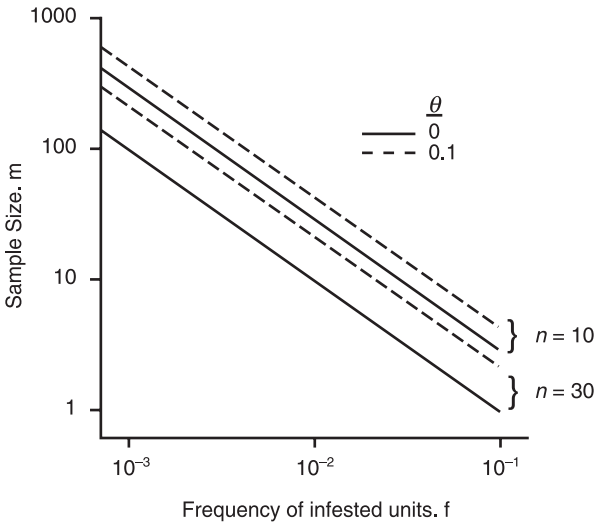

Fig. 1 Required sample size (m) to detect one or more individuals with 95% confidence as affected by the proportion of a commodity that is infested, batch size, and the degree of aggregation (θ; if θ = 0, no aggregation), assuming beta binomial statistics apply (from Venette *et al*., 2002).

ICPM (2004) Glossary of Phytosanitary Terms. *International Standard for Phytosanitary Measures* no. 5. FAO, Rome (IT).

Venette RC, Moon RD & Hutchinson WD (2002) Strategies and statistics of sampling for rare individuals. *Annual Review of Entomology* **47**, 143–174.

Ward MG (1994) Sampling to make decisions in the Plant Health and Seeds Inspectorate. *Aspects of Applied Biology* **37**, 217–224.

Appendix

Sampling of large consignments: binomial based sampling

For large consignments sufficiently mixed, the likelihood of finding an infested unit is approximated by simple binomial statistics. The sample size is less than 5% of the consignment or lot size. The probability of observing X infested units in a sample of n units is given by:

$$P\ (X = 1) = \left(\frac{n}{i}\right) f^i (1 - f)^{n-i}$$

f is the average proportion of infested units (infestation level) in the consignment, and $P(X = i)$ is the probability of observing i infested units in the sample (the Confidence Level referred to in Table 2 corresponds to $(1 - P(X = i))$.

For phytosanitary purposes, the probability of not observing an infested unit in a sample of n units is given by

$$P(X = 0) = (1 - f)^n$$

The probability of observing at least one infested unit is then:

$$P(X > 0) = 1 - (1 - f)^n$$

This equation can be rearranged to determine n

$$n = \frac{\ln[1 - P(X > 0)]}{\ln(1 - f)}$$

The size of the consignment can be determined with this equation when the infestation level (f) and the confidence level ($1 - P(X > 0)$) are fixed by the NPPO.

Sampling of small consignments: hypergeometric-based sampling

The hypergeometric distribution is appropriate for determining the probability of finding a pest in a relatively small consignment. A consignment is considered as small when the sample size is more than 5% of the consignment or lot size. In this case, when an unit is sampled from the consignment, the probability of finding an infested unit in the next unit selected changes.

Comparison between fixed sampling and hypergeometric-based sampling

As shown in Table 1, sampling a fixed proportion of a consignment may provide too few or too many observations to achieve a desired probability of detection.

The probability of detecting i infested units in a sample is given by:

$$P(X = i) = \frac{\left(\frac{X}{i}\right)\left(\frac{N - X}{n - i}\right)}{\left(\frac{N}{n}\right)}$$

Where:

$$\left(\frac{a}{b}\right) = \frac{a!}{b!(a - b)!}$$

$P(X = i)$ is the probability of observing i infested units in the sample (the Confidence Level referred to in appendix 2 corresponds to: $(1 - P(X = i))$

X = number of infested units in the consignment or lot

i = number of infested units in the sample

N = number of units in the consignment (size of the consignment or lot)

n = number of units in the sample (sample size).

Solving the equation to determine n is difficult arithmetically but can be done by approximation or through maximum likelihood estimation. It has been done for different consignment or lot sizes, confidence levels and possible infestation levels in Tables 2(a) and 2(b).

Sampling for pests with an aggregated distribution: beta-binomial based sampling

In the case of aggregated special distribution, sampling plans can be adjusted to compensate for aggregation. For this adjustment to apply, it should be assumed that the commodity is sampled in batches (e.g. boxes) and that each unit in a chosen batch is examined (cluster sampling). In such cases, f is no longer constant across all clusters but will follow a beta density function.

$$P(X = i) = \binom{n}{i} \frac{\prod_{j=0}^{i-1}(f + j\theta) \prod_{j=0}^{n-i-1}(1 - f + j\theta)}{\prod_{j=0}^{n-1}(1 + j\theta)}$$

f is the average proportion of infested units (infestation level) in the consignment

$P(X = i)$ is the probability of observing i infested units in a batch

n = number of units in a batch

Π is the product function

θ provides a measure of aggregation for the jth batch

θ is $0 < \theta < 1$.

Phytosanitary sampling is often more concerned with the probability of not observing an infested unit after inspecting several batches. For a single batch, the probability that $x = 0$ is $P(X = 0) = 1 - \prod_{j=0}^{n-1}(1 - f + j\theta)/(1 + j\theta)$ and the probability that each of several batches has no infected unit, $\Pr(X = 0)$, equals $P(X = 0)^m$, where m is the number of batches. When f is low, equation 1 can be estimated by

$P(X = 0) \approx (1 - n\theta)^{-(f/\theta)}$

$\Pr(X = 0) \approx (1 + n\theta)^{-(mf/\theta)}$

The probability of observing one or more infected unit is given by $1 - \Pr(X = 0)$.

This equation can be rearranged to determine m

$$m = \frac{-\theta}{f}\left[\frac{\ln(1 - P(X > 0)}{\ln(1 + n\theta)}\right]$$

When the degree of aggregation and the level of confidence are fixed, the size of the sample can be determined.

The effect of aggregation can be seen in Fig. 1.