Modeling the Rejection Probability in Plant Imports

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Accepted for publication 8 January 2008.

ABSTRACT

Surkov, I. V., van der Werf, W., van Kooten, O., and Oude Lansink, A. G. J. M. 2008. Modeling the rejection probability in plant imports. *Phytopathology* 98:728-735.

Phytosanitary inspection of imported plants and flowers is a major means for preventing pest invasions through international trade, but in a majority of countries availability of resources prevents inspection of all imports. Prediction of the likelihood of pest infestation in imported shipments could help maximize the efficiency of inspection by targeting inspection on shipments with the highest likelihood of infestation. This paper applies a multinomial logistic (MNL) regression model to data on import inspections of ornamental plant commodities in the Netherlands from 1998 to 2001 to investigate whether it is possible to predict the probability that a shipment will be (i) accepted for import, (ii) rejected for import because of detected pests, or (iii) rejected due to other reasons. Four models were estimated: (i) an all-species model, including all plant imports (136,251 shipments) in the data set, (ii) a four-species model,

including records on the four ornamental commodities that accounted for 28.9% of inspected and 49.5% of rejected shipments, and two models for single commodities with large import volumes and percentages of rejections, (iii) *Dianthus* (16.9% of inspected and 46.3% of rejected shipments), and (iv) *Chrysanthemum* (6.9 and 8.6%, respectively). All models were highly significant ($P < 0.001$). The models for *Dianthus* and *Chrysanthemum* and for the set of four ornamental commodities showed a better fit to data than the model for all ornamental commodities. Variables that characterized the imported shipment's region of origin, the shipment's size, the company that imported the shipment, and season and year of import, were significant in most of the estimated models. The combined results of this study suggest that the MNL model can be a useful tool for modeling the probability of rejecting imported commodities even with a small set of explanatory variables. The MNL model can be helpful in better targeting of resources for import inspection. The inspecting agencies could enable development of these models by appropriately recording inspection results.

International trade is considered as the major vector for spread of nonindigenous pests and pathogens (henceforth, pests) in the world (5,18,24,28). Introduction and establishment of pests in importing countries may lead to significant economic losses (25,29). Border phytosanitary inspection of incoming commodities is a major means for preventing pest invasion with international trade.

The quantity of imported commodities requiring inspection is increasing as a consequence of a general growth of world trade. For example, it has been reported that an increasing percentage of air cargo imported in the United States consists of cut flowers, fruits, and vegetables (23). In Japan, a 150-fold increase in the quantity of the inspected cut flowers was observed between 1970 and 1998 (19). The number of commodity pathways (commodity-exporting country combinations) to be inspected is also increasing. This may reflect both the natural emergence of new import pathways (e.g., a given country starts exporting a commodity that it did not export before) and also the inclusion of new pathways requiring inspection according to legislation of the importing countries. For example, the recently enacted European Council Directive 2000/29/EC implied a significant increase in the number of commodities and pathways that require inspection upon import in the European Union (EU) (10).

Overall, there is a significant pressure on inspecting agencies to provide an adequate level of inspection of imported commodities. In fact, given the usually limited resources of the inspecting agencies (24), a complete inspection of all commodities is almost impossible (34). Some importing countries have attempted to address this problem by allowing for a reduced inspection fre-

quency of commodities. For example, under the "reduced checks" system recently introduced in the EU (9), the proportion of inspected shipments of some commodity pathways (e.g., cut flowers and fruits) may be reduced compared with normal (i.e., 100%) levels. In the United States, inspection is based on a random sampling within the population of incoming commodities (33). When only a fraction of the overall population of commodity pathways (or shipments within commodities pathways) can be inspected, it is crucial to make a proper choice of which objects are inspected. A quantitative analysis of factors that influence the probability of rejection of imported commodities because of pest infestation can be very helpful in designing efficient inspection schemes. There has been limited research in this area (2,6,7). Although there have been studies that have quantitatively analyzed pest interceptions pertaining to (groups of) specific commodities (4,12,16,20,27,36), their results cannot be easily generalized to a context of multiple commodities, nor do these studies provide a priori predictions for new pathways. Thus, there is a need for general models that would allow prediction of the risk of pest infestation across commodities and countries of origin, such that *ex ante* risk assessments could be made before familiarity with a new import pathway is obtained during import practice.

The objective of this paper was to investigate whether the probability of rejecting imported shipments due to phytosanitary and nonphytosanitary reasons can be predicted on the basis of generally available variables characterizing the shipment of an imported commodity and the shipment's country of origin. A multinomial logistic (MNL) regression was fitted to the data set with results of phytosanitary inspections of ornamental plant commodities imported in the Netherlands from 1998 to 2001. An MNL model is a polytomous version of the binary logistic regression, which is a common modeling and explanatory tool in

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doi:10.1094/PHYTO-98-6-0728

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plant pathology (15). An MNL is used in this study because commodities may be rejected for import due to both phytosanitary (i.e., a pest is found) and nonphytosanitary reasons (e.g., poor quality of the commodity or the absence of required documents). Nonphytosanitary reasons for rejecting shipments may actually indicate potential phytosanitary problems associated with an imported shipment. Therefore, an MNL model can generate useful insights into factors underlying quality problems in imported commodities both on phytosanitary and nonphytosanitary grounds. Furthermore, as the MNL model essentially represents a linked set of binary logistic models, parameter estimates in the MNL model are consistent with parameter estimates of the binary logistic models (30).

To test the generality of the parameter estimates of the MNL model, it was fitted to all ornamental commodities in the data set, to a subset of ornamental commodities and to single ornamental commodities. Therefore, the following questions were addressed: (i) Can the probability of pest infestation be predicted using an MNL model? (ii) What is the explanatory power of an MNL model in this context? (iii) Is it possible to build a general model that can be used across different commodities and countries or regions of origin, or can predictions only be made for specific commodity-country combinations? (iv) And which variables characterizing imported shipments can be considered as risk or nonrisk factors, indicative of, respectively, high and low probability of pest infestation?

MATERIALS AND METHODS

Data collection. Data were obtained from the Dutch Plant Protection Service (PPS). These data contained results of phytosanitary inspections of ornamental plant commodities (cut flowers, ornamental plants, and materials for propagation) that were imported in the Netherlands from 9 February 1998 to 31 December 2001. There were 136,251 records in the data set. Each record represented a single shipment of an ornamental commodity from a single exporting country. At the moment of inspection, a single shipment may have consisted of smaller units (lots) that could be distinguished by, for example, a cultivar or producer (J. Schans, PPS, *personal communication*), but this information was not retained in the data set. Thus, a record of inspection of one shipment was the smallest unit for the numerical analyses presented here.

For every record in the data set, the following information was available: the name and the exporting country of an ornamental commodity; the shipment's size, the quantity of commodity units (e.g., cut flower stems) in the individual lot(s) within a single data set record; the unique number of a Dutch importing company; the inspection report number; the date of inspection; the outcome of inspection ("rejected" or "imported"); and the reasons of rejection of a shipment. The reasons of rejection could be phytosanitary and nonphytosanitary. Phytosanitary reasons for rejection mean that a pest was found in a shipment. Nonphytosanitary reasons for rejection of shipments included the absence or incomplete/incorrect filling in of the necessary documents (such as the phytosanitary certificate) or an inadequate quality of the commodity (e.g., wilted cut flowers). The data set was examined to make sure that each record was classified as "rejected due to phytosanitary reasons," "rejected due to nonphytosanitary reasons," or "not rejected."

In total, 881 shipments (0.65% of all shipments) were marked as rejected for import in the Netherlands during the 1998 to 2001 reporting period. Of these shipments, 456 (0.33% of all shipments) were marked as rejected due to findings of pests and 425 shipments were marked as rejected due to other reasons. Pests that caused the rejection of a given shipment had to be of quarantine significance and mentioned in plant health directives of the EU (8,10).

Upon a decision to reject a plant import, the general PPS practice was to split the original shipment that had been found infested during import inspection into an infested and a non-infested part (if such splitting was possible based on unique and objective criteria, such as supplier in the exporting country, variety, or other criteria) (J. Schans, PPS, *personal communication*). If splitting had occurred, information on the infested and noninfested parts of a shipment was entered in the data set as two separate records. This practice could artificially affect a relationship, if extant, between the size of plant imports and the probability of rejection, for example, by making the rejection of shipments of particular size more or less likely. We considered splitting possible if under the same inspection report number, more than one record of the same commodity from the same exporting country with an infested record was present. Otherwise, splitting was considered impossible. Approximately 40% of records of rejected shipments were identified as possibly being formed by the splitting of original shipments.

Statistical analyses were conducted on both the data sets containing all the records and the one containing only records for which splitting of rejected shipments was considered impossible. The results were practically identical irrespective of which underlying data set was used. Therefore, all the results reported in this paper are based on the entire data set of import inspections.

Explanatory variables. The International Standard on Phytosanitary Measures (ISPM) No 23 "Guidelines for Inspection" issued by FAO (Food and Agricultural Organization of the United Nations) (11) was followed as a guidance for selecting relevant explanatory variables. The ISPM No. 23 lists factors that may be considered when making a decision to use inspection as a phytosanitary measure. Based on this standard, the variables that described (i) exporting country, (ii) commodity, (iii) importing company, (iv) shipment, and (v) year and season of import, were specified. In addition, further explanatory variables representing the economic and geographic characteristics of the exporting country using the data obtained from the Dutch Agricultural Economics Research Institute (32) were considered. Table 1 presents the explanatory variables and their descriptive statistics.

Exporting country characteristics. The first 11 variables in Table 1 represented geographical regions and income classes of the exporting countries according to the World Bank classification (37). The following three variables characterized the importance of agricultural exports to the exporting country: AGRTOT (the share of agricultural exports in total exports), CUT (the share of exports of cut flowers in agricultural exports), and PLANT (the share of export of potted plants in agricultural exports). These variables were included to test the hypothesis that the exporting country's agricultural specialization could influence the probability of rejecting a shipment.

Commodity characteristics. The binary variables DIANTHUS, CHRYS, FICUS, and DENDROB represented the ornamental plants in genera *Dianthus*, *Chrysanthemum*, *Ficus*, and *Dendrobium*, that from 1998 to 2001, collectively accounted for 68% of shipments rejected due to the presence of pests and 29% of shipments rejected on nonphytosanitary grounds. Furthermore, shipments of these ornamental commodities accounted for approximately a third of all inspected shipments (Table 1).

Importing company characteristics. The variables NSPECIES and D1000+ tested whether shipments destined for Dutch companies importing, respectively, many different ornamental species or many shipments of ornamental species, had greater probabilities of being rejected. PHYTOM is a binary variable equal to one if the company that imported the shipment possessed the quality certificate "Phytomark." From 2000 to 2003, this certificate was conferred on Dutch companies that complied with a set of rules, representing good phytosanitary and quality practices in horticultural production.

Characteristics of a shipment. LOG_SIZE is the natural logarithm of the number of units (e.g., cut flowers, potted plants, or cuttings) in a shipment. This variable was used to test whether the size of a shipment was important in predicting the likelihood of rejecting a shipment.

Season and year of import. The last eight binary variables (Table 1) represented the season and year of import of a shipment. These variables were included in the model to test the hypothesis that the likelihood of rejecting shipments was significantly associated with seasons or years of import.

For 4,554 records (3.34% of the data set) the values for the variables representing export characteristics (AGRTOT, CUT, and PLANT) were missing. Missing data mostly pertained to smaller exporting countries with limited data availability. We replaced the missing values by the averages of variables AGRTOT, CUT, and PLANT calculated for the countries belonging to the same income class as the country for which data were missing. After replacement, 161 (0.12% of the data set) missing values were left; these values were omitted from the analysis.

Correlations between variables. Possible correlations between explanatory variables were examined using PROC CORR procedure of SAS (SAS Institute Inc., Cary, NC). Correlations between continuous variables were examined using Pearson correlation coefficients. Correlations between continuous and binary variables were examined using nonparametric Kendall correlation coefficients. Associations between binary variables were tested using two-way contingency tables; null hypotheses of independence were explored using chi-square tests (22).

The MNL regression model. Three mutually exclusive outcomes were defined as the response variable for import inspections (i) a shipment is accepted for import, (ii) a shipment is rejected due to the presence of a pest, and (iii) a shipment is rejected due to other reasons. The MNL model (30) predicts the probability of observing one of the above outcomes for the i th shipment of ornamental species with a given set of explanatory variables. For estimation purposes, the above outcomes were assigned values 0, 1, and 2, respectively. The probability to observe the j th ($j = 0, 1, 2$) inspection outcome for the i th imported shipment is given by

$$prob(Y_i = j | X_i) = \frac{\exp(\beta_j' X_i)}{\sum_{j=0}^2 \exp(\beta_j' X_i)} \quad j = 0, 1, 2$$

where $\beta_j' X_i$ represents $\sum_k \beta_{kj} x_{ik}$, and β_{kj} are the k parameters to be estimated for j inspection outcomes and X_i is the vector of k explanatory variables.

Because the probabilities of alternative inspection outcomes should sum up to one, it was sufficient to estimate equations for two inspection outcomes. One inspection outcome, shipment is not rejected ($j = 0$), was thus dropped from estimation and represented the reference situation. The corresponding parameter vector was $\beta'_0 = 0$. Parameter estimates β_{kj} for the other two outcomes represent the change in the natural logarithm of odds of rejection due to pest or due to other reasons, relative to the reference outcome (shipment is not rejected), following a unit change in the independent variable x_k . Thus, the change in the

TABLE 1. Descriptive statistics of the explanatory variables, $n = 136,075$

Variable	Description	Mean	Standard deviation
Variables related to the exporting country			
RMN ^a	Situated in Middle East and North Africa	0.26	0.44
REU ^a	Situated in Europe and Central Asia	0.07	0.26
REA ^a	Situated in East Asia and Pacific	0.14	0.34
RLA ^a	Situated in Latin America and the Caribbean	0.28	0.45
RNA ^a	Situated in North America	0.02	0.15
RSA ^a	Situated in South-East Asia	0.05	0.21
RSS ^a	Situated in Sub-Saharan Africa	0.18	0.38
I1 ^{ab}	Is a low income country	0.18	0.38
I2 ^a	Is a middle low income country	0.41	0.49
I3 ^a	Is a middle high income country	0.10	0.30
I4 ^a	Is a high income country	0.32	0.47
AGRTOT	Share of agricultural exports in total exports	27.1	22.9
CUT	Share of cut flowers in agricultural exports ^c	61.3	58.4
PLANT	Share of pot plants in agricultural exports ^c	14.7	15.2
Variables related to imported commodity			
DIANTHUS ^a	Dianthus (<i>Dianthus caryophyllus</i> L.)	0.17	0.37
CHRYSA ^a	Chrysanthemum (<i>Chrysanthemum</i> L.)	0.07	0.25
FICUS ^a	Ficus (<i>Ficus</i> L.)	0.03	0.17
DENDROB ^a	Dendrobium (<i>Dendrobium</i> Sw.)	0.03	0.16
Variables related to importing company			
NSPECIES	The number of different ornamental species imported by a single importing company	83.32	78.52
D1000+ ^a	Importing company with volume of import greater than 1,000 shipments	0.58	0.49
PHYTOM ^a	Importing company possessing the Phytomark certificate	0.11	0.31
Variables related to shipment			
LOG_SIZE	Natural logarithm of shipment size	8.39	2.59
Variables representing season and year of import			
S1 ^a	December, January, or February	0.28	0.45
S2 ^a	March, April, or May	0.31	0.46
S3 ^a	June, July, or August	0.20	0.40
S4 ^a	September, October, or November	0.21	0.41
Y98 ^a	Year 1998	0.21	0.41
Y99 ^a	Year 1999	0.25	0.43
Y00 ^a	Year 2000	0.27	0.44
Y01 ^a	Year 2001	0.27	0.45

^a Binary variable, equal to one if a record satisfies the property and 0 otherwise.

^b Binary variables of income class do not sum up to one due to rounding.

^c Calculated as cut flowers (pot plants)/overall agricultural exports $\times$ 1,000. The factor 1,000 is used because in many countries the shares of cut flowers and pot plants in agricultural exports are negligible.

odds of obtaining one of the two inspection outcomes versus the reference outcome is given by $\exp(\beta_{kj})$. In general, a positive value of the estimated parameter implies that the probability of rejection due to pest or due to other reasons increases, while a negative value indicates the opposite.

The MNL model was estimated using maximum likelihood. The adequacy of the model was assessed using the likelihood ratio (LR) χ^2 test statistic with a null hypothesis that all $\beta_{kj} = 0$. The model fit was assessed using R^2_L (21), a logistic regression analog of a coefficient of determination in linear models. R^2_L is calculated as $1 - \ln L(\text{Full}) / \ln L(0)$, where $\ln L(\text{Full})$ is the log-likelihood of a model with all explanatory variables while $\ln L(0)$ is the log-likelihood of a model with the intercept only. A greater value of the R^2_L generally indicates a better model fit. However, the absolute magnitude of R^2_L measures used in logistic regression is generally considerably lower than of the R^2 in linear models (21).

Estimated models. Four models were estimated using the same set of explanatory variables. The “all-species” model included all records in the data set. The “4-species” model included records pertaining to four genera of ornamental plants: *Dianthus*, *Chrysanthemum*, *Dendrobium*, and *Ficus*. The remaining two models, denoted “Dianthus” and “Chrysanthemum,” included records on the respective genera of ornamental plants only. The rationale for the four models is that from the inspection policy perspective, it is preferable to have a general model that can be applied to all ornamental commodities (all-species model), however, it is a priori questionable whether regression coefficients are consistent across commodities. For instance, in one commodity there may be a systematic trend that shipments from Asia are less often rejected than those from Africa, whereas for another commodity, the trend could be reversed. Thus, it may occur that models applied to subsets of the data provide a better explanation of those data than an overall model. The parameterization of models with one, few, or many ornamental commodities served a purpose to explore the generality of parameter estimates in the MNL models as a tool in the prediction of likelihood of rejection in plant imports.

All models were estimated using the NOMREG procedure in SPSS 12.0 (SPSS Inc., Chicago, IL). NOMREG uses the iterative Newton-Raphson algorithm that searches the maximum likelihood estimates of the parameter values, starting from the initial “guess” values (29). The process continues until the model reaches convergence. Estimated equations for the 4-species and all-species models included all explanatory variables in order to have a general view on the significance of the explanatory variables for predicting the likelihood of rejecting shipments. Single species models, on the other hand, a priori are likely to be species-specific. Therefore, in the Dianthus and Chrysanthemum models, the SPSS backward elimination procedure that sequentially eliminated nonsignificant variables at $P = 0.1$ (χ^2 test) was used to select the best set of explanatory variables.

Only $k - 1$ binary variables representing geographical region, income class, season, and year of import, and individual ornamental commodities (in 4-species model) had to be estimated for each group of these variables (with k values) to avoid redundancy. One binary variable for each of these groups was omitted, creating thus a reference situation with which the obtained parameter estimates should be compared. In all the models, the reference situation represented a shipment imported in 1998 (Y1998), from a high-income country (I4), and imported in winter (S1). In addition, in the all-species model, there was also a reference region (Middle East and North Africa [RMN]), and in the 4-species model, a reference commodity (*Ficus*).

Prior to estimation, binary variables in all models were examined for data separation (1). Data separation occurs when an explanatory variable has no records pertaining to one or more categories of the dependent variable. If such a predictor is left in the model, its maximum likelihood estimate may not exist (1). In

the 4-species and Dianthus and Chrysanthemum models we detected a number of variables that suffered from data separation. We subsequently omitted the variables from the estimated equations.

RESULTS

Correlations. High and significant correlations were found between continuous variables AGRTOT, CUT, and PLANT in data sets of all four estimated models. The variable PLANT was omitted from all estimated equations as it was highly correlated with the other two variables. Furthermore, high and significant ($P < 0.001$) correlations were found between the variables AGRTOT and CUT and some of the binary variables representing geographical position and income class of an exporting country. These correlations were used for interpreting estimation results (22).

Results of the 4-species and all-species models. Likelihood ratio χ^2 statistics shows that the 4-species and all-species models were highly significant ($P < 0.001$) (Table 2). According to R^2_L , the 4-species model fitted data better than the all-species model.

The share of agricultural export in total exports was positively and significantly ($P < 0.05$) associated with the likelihood of rejecting a shipment in the 4-species model. The share of cut flower export in agricultural exports was a highly significant ($P < 0.001$) and negative predictor of the likelihood of rejection in the all-species model. Parameter estimates indicate that shipments coming from Europe or Latin America were significantly less likely to be rejected on phytosanitary grounds than shipments coming from other regions (4-species model) and the reference region (Middle East and North Africa, all-species model). Furthermore, parameter estimates of regional variables RNA (North America) and RSA (South-East Asia) were also significant ($P < 0.05$) and negative in the all-species model. However, none of the regional variables in both models was significant in predicting the probability of rejecting shipments due to nonphytosanitary reasons.

Variables representing the income class of an exporting country did not show a significant association with the likelihood of rejecting shipments on phytosanitary grounds in the 4-species or all-species model. This lack of statistical significance is due to high correlations observed between variables representing the income class of exporting countries and the variables AGRTOT and CUT. For example, high-income countries (variable I4) tended to have a greater share of agricultural exports in total exports and lower shares of cut flower exports in agricultural exports. When the 4-species and all-species models were estimated without variables AGRTOT and CUT, most income variables became significantly associated with the likelihood of rejecting shipments on phytosanitary grounds. At the same time, positive parameter estimates of variables representing low (I2) and middle high (I3) income countries in the all-species model suggest that shipments coming from poorer countries are less likely to be rejected due to nonphytosanitary reasons than shipments coming from a high income (reference) country.

The variable NSPECIES was highly significant ($P < 0.001$) and had a negative regression coefficient in both the 4-species and all-species models, indicating that shipments destined for Dutch companies importing a larger variety of ornamental species were *ceteris paribus* less likely to be rejected due to phytosanitary reasons. A positive value of the coefficient for D1000+ ($P < 0.001$) suggests that shipments destined for importing companies with a large number of imported shipments had a higher probability of being rejected due to the presence of a pest. Given the high negative correlation found between NSPECIES and D1000+ (Kendall $\tau = -0.55$, $P < 0.001$), the above findings suggest that companies with large volumes of imported shipments specialized on import of fewer ornamental species that had greater likelihoods of bringing pests.

The variable LOG_SIZE (natural logarithm of shipment size) has a negative regression coefficient and was a highly significant ($P < 0.001$) predictor of the probability of rejecting shipments due to phytosanitary reasons in both models. Moreover, this variable was a significant ($P < 0.001$) predictor of the probability to reject shipments due to nonphytosanitary reasons for ornamental species included in the 4-species model. Possession of the Phytomark certificate by the importing company significantly ($P < 0.05$) decreased the likelihood of rejecting shipments destined for this company on phytosanitary grounds in both the 4-species and all-species model. On the other hand, the results do not suggest that possession of Phytomark was significantly related to the likelihood of rejecting shipments on nonphytosanitary grounds. Parameter estimates of DIANTHUS and DENDROB (in the 4-species and all-species models) and CHRYS and FICUS (in the all-species model only) imply that plants in these genera were *ceteris paribus* significantly more likely to be rejected due to the presence of a pest than plants from other genera. The values of parameter estimates imply a considerable increase in the odds of rejecting shipments of these ornamental commodities due to phytosanitary reasons. For example, the odds of rejection increase with a factor of $e^{2.595} = 13.4$ for shipments of Dianthus (compared with non-Dianthus shipments) and with a factor of $e^{1.596} = 4.9$ for shipments of Chrysanthemum (compared with non-Chrysanthemum shipments).

Parameter estimates of the variables S2 and S4 suggest that shipments imported in the spring and autumn seasons were *ceteris paribus* more likely to be rejected due to the presence of a pest compared to shipments imported in winter (a reference season). Finally, estimates of year variables in both models indicate that shipments imported in 1999 and 2000 had a significantly lower probability of rejection due to the presence of a pest compared with shipments imported in 1998.

Results of the Dianthus and Chrysanthemum models. Both models were highly significant ($P < 0.001$) according to the LR χ^2

test statistic (Table 3). The fit of the Dianthus model was substantially better than that of the Chrysanthemum model, according to R^2_L . Only one regional variable, RMN (Middle East and North Africa), was significantly ($P < 0.05$) and positively associated with the probability to reject shipments of Dianthus on phytosanitary and nonphytosanitary grounds. Shipments of Dianthus originating from countries in Latin America were *ceteris paribus* more likely to be rejected due to nonphytosanitary reasons than shipments originating from other regions.

The results suggest that shipments of Dianthus imported from low and middle-high income countries were more likely to be rejected on phytosanitary grounds than shipments imported from high-income countries. The impact and significance of estimated variables NSPECIES, D1000+, LOG_SIZE, S2, and S4 in the Dianthus model were very similar to their impact in the 4-species model.

Parameter estimates of AGRTOT ($P < 0.001$) and CUT ($P < 0.05$) suggest that shipments of Chrysanthemum imported from countries with relatively larger shares of, respectively, agricultural exports and exports of cut flowers were more likely to be rejected because of the presence of a pest. None of the regional variables in the Chrysanthemum model was statistically significant. Income variables, conversely, appeared significant ($P < 0.05$) positive predictors of the probability of rejecting shipments of Chrysanthemum coming from lower income countries due to nonphytosanitary reasons. The probability of rejecting shipments of Chrysanthemum due to nonphytosanitary reasons was higher for larger importers, as indicated by variable D1000+ ($P < 0.001$). The variable LOG_SIZE was a significant ($P < 0.001$) negative predictor of the likelihood of rejecting shipments of Chrysanthemum on nonphytosanitary grounds.

Parameter estimates of the year variables indicate significant annual variability in the probability of rejecting shipments of Dianthus (due to both reasons) and Chrysanthemum due to nonphytosanitary reasons.

TABLE 2. Parameter estimates of the 4-species and all-species multinomial logistic (MNL) models (with standard errors in parenthesis)

Independent variables	Estimated models ^a			
	4-species model		All-species model	
	Rejection due to pest	Rejection due to other reason	Rejection due to pest	Rejection due to other reason
Intercept	-3.096 (0.474)***	-5.047 (0.581)***	-3.069 (0.309)***	-4.902 (0.33)***
AGRTOT	0.029 (0.011)*	0.026 (0.013)*	0.007 (0.006)	0.004 (0.005)
CUT	-0.003 (0.003)	-0.006 (0.003)	-0.010 (0.002)***	-0.006 (0.002)***
REU	-1.545 (0.517)*	-0.406 (0.548)	-1.710 (0.349)***	0.031 (0.278)
REA	0.151 (0.424)	-0.102 (0.662)	-0.313 (0.247)	-0.161 (0.275)
RLA	-1.635 (0.411)***	-0.261 (0.545)	-1.085 (0.252)***	0.179 (0.266)
RNA			-1.455 (0.438)***	-0.385 (0.373)
RSA			-1.258 (0.471)*	-0.005 (0.350)
RSS	-0.823 (0.582)	-0.055 (0.739)	-0.432 (0.346)	0.331 (0.357)
I1	0.147 (0.682)	-0.693 (0.933)	-0.015 (0.356)	-0.249 (0.307)
I2	-0.152 (0.273)	-0.189 (0.414)	-0.369 (0.195)	-0.679 (0.208)*
I3	0.989 (0.544)	0.177 (0.684)	0.100 (0.281)	-0.883 (0.257)***
NSPECIES	-0.008 (0.001)***	-0.001 (0.002)	-0.007 (0.001)***	0.000 (0.001)
D1000+	1.349 (0.156)***	0.218 (0.238)	0.814 (0.118)***	-0.593 (0.149)***
LOG_SIZE	-0.404 (0.023)***	-0.217 (0.038)***	-0.319 (0.018)***	-0.038 (0.021)
PHYTOM	-0.923 (0.353)*	0.187 (0.334)	-0.665 (0.261)*	-0.243 (0.199)
DIANTHUS	1.785 (0.354)***	1.218 (0.427)*	2.595 (0.161)***	0.406 (0.165)*
CHRYS	0.735 (0.385)	0.915 (0.463)*	1.596 (0.225)***	0.094 (0.233)
FICUS			0.818 (0.286)*	-0.006 (0.313)
DENDROB	1.302 (0.442)*	-0.395 (0.833)	1.977 (0.226)***	-0.868 (0.530)
S2	0.548 (0.157)***	-0.299 (0.245)	0.489 (0.127)***	-0.267 (0.138)
S3	-0.239 (0.244)	0.012 (0.268)	-0.163 (0.179)	0.195 (0.139)
S4	0.538 (0.182)*	0.005 (0.252)	0.359 (0.148)*	0.118 (0.137)
Y99	-0.998 (0.177)***	0.912 (0.260)***	-0.597 (0.137)***	0.718 (0.146)***
Y00	-0.769 (0.179)***	0.321 (0.293)	-0.523 (0.138)***	0.242 (0.158)
Y01	0.026 (0.149)	-0.284 (0.346)	-0.129 (0.127)	0.005 (0.166)
Number of records	39,345	39,345	136,075	136,075
χ^2 statistic	693 (44 df)		1,067 (50 df)	
R^2_L	0.130		0.090	

^a Variables FICUS, I4, S1, Y98 (4-species model) and RMN, I4, S1, Y98 (all-species model) were omitted to avoid redundancy. Variables RSA and RNA (4-species model) model were removed due to data separation problem. * $P < 0.05$, ** $P < 0.01$, and *** $P < 0.001$.

Comparison of models. The differences between the 4-species and all-species models were small compared with the differences between the *Dianthus* and *Chrysanthemum* models. The closeness of results of the former two models is mainly because the four ornamental species in the 4-species model accounted for most of the rejected shipments in the all-species model, and for a considerable proportion of inspected shipments in the overall data set. Thus, most statistically significant variables in the 4-species model were also significant in all-species model. However, the overall fit of the all-species model was still notably lower ($R^2_L = 0.090$) than that of the 4-species model ($R^2_L = 0.130$).

After backward elimination, a larger number of significant variables remained in the *Dianthus* model than in the *Chrysanthemum* model. Most notably, none of the regional and seasonal variables that were significant in the *Dianthus* model appeared in the estimated equation for *Chrysanthemum*. As a result, the fit of the *Dianthus* model was substantially higher than that of the *Chrysanthemum* model. In general, *Dianthus* and *Chrysanthemum* models showed a better fit to data than 4-species and all-species models. This suggests that independent variables are the best predictors of the likelihood of rejecting shipments of individual ornamental species.

Parameter estimates in the single species models suggest possible interpretations of results of multi-species models. Similarities of parameter estimates of variables NSPECIES, D1000+, LOG_SIZE, and seasonal and year variables, in *Dianthus* and 4-species models suggest that inclusion of records on *Dianthus* in the latter model to a large extent influenced the parameter estimates.

DISCUSSION

This study showed that a multinomial logistic model can be used to predict the probability that an imported shipment of an ornamental species is rejected due to the presence of a pest or due to other reasons. Explanatory variables characterizing an imported shipment were significantly ($P < 0.001$) associated with the likelihood of rejecting shipments in all the estimated models. The results of the 4-species and all-species models suggest the best risk factors to predict the likelihood of rejecting shipments due to the presence of a pest: (i) geographical regions of exporting countries, (ii) the size of the shipment, (iii) the ornamental plants in specific genera, and (iv) variables representing the season and

year of import. These factors were also relevant for predicting the likelihoods of rejecting shipments of individual ornamental commodities (*Dianthus* and *Chrysanthemum*) but there can be substantial variation among significant factors depending on particular commodity. Models representing individual ornamental species *Dianthus* and *Chrysanthemum* showed the best fit to data. With addition of records on other ornamental species, the fit of models deteriorated while the realm of possible application enlarged. The decrease in explanatory power with increasing diversity of commodities is likely because many different and perhaps conflicting explanatory factors may influence likelihoods of rejecting shipments of ornamental species included in multi-species models. Thus, the results suggest that the MNL regression is best to be applied in single species models for which the impact of specific factors can best be singled out.

Because MNL models have not been applied before in a phytosanitary context, it is impossible to directly compare the results of this study with other studies. The results, though, support findings (2,14) that likelihoods of rejecting shipments on phytosanitary grounds vary significantly between ornamental plants in different genera. The results indicate that likelihoods of rejecting imported shipments are significantly associated with certain regions of the world (e.g., Middle East and North Africa). However, these results should not be taken to imply that shipments imported from all countries situated in a given region pose the same risk. In the present case, most rejected shipments from the Middle East and North Africa were associated with Israel, which was also the largest exporting country to the Netherlands in the period of 1998 to 2001. The impact of a certain country can be investigated by including a relevant binary variable in the estimated equations. Such a pathway analysis was performed for *Dianthus* and *Chrysanthemum* (data not shown). The results indicate that shipments coming from certain countries have significantly higher probabilities of being rejected due to the presence of a pest. However, introduction of country variables may increase the likelihood of the data separation problem, because of a significantly smaller number of records pertaining to a single country and, thus, a greater likelihood that available records do not fall within all the categories of the dependent variable. Data separation did not allow testing the impacts of some regional variables in the 4-species model and of most of the regional variables in the *Dianthus* and *Chrysanthemum* models.

TABLE 3. Parameter estimates of the *Dianthus* and *Chrysanthemum* multinomial logistic (MNL) models (standard errors in parenthesis)

Independent variables	Estimated models ^a			
	<i>Dianthus</i>		<i>Chrysanthemum</i>	
	Rejection due to pest	Rejection due to other reason	Rejection due to pest	Rejection due to other reason
Intercept	-2.916 (0.759)***	-3.075 (0.806)***	-5.219 (1.207)***	-8.310 (1.402)***
AGRTOT			0.083 (0.022)***	0.005 (0.014)
CUT	0.001 (0.005)	-0.017 (0.003)***	0.015 (0.007)*	0.006 (0.006)
RMN	1.553 (0.66)*	1.274 (0.604)*		
RLA	-0.511 (1.015)	2.134 (0.755)*		
I1	3.292 (0.614)***	0.892 (0.609)	-3.510 (1.259)*	3.404 (1.405)*
I2	0.691 (0.437)	-1.090 (0.511)*	-0.946 (0.877)	2.743 (1.293)*
I3	3.126 (1.001)*	-0.394 (1.018)	1.604 (0.931)	2.999 (1.324)*
NSPECIES	-0.015 (0.002)***	0.001 (0.002)		
D1000+	1.815 (0.232)***	-0.321 (0.356)	0.380 (0.395)	1.401 (0.413)***
LOG_SIZE	-0.451 (0.032)***	-0.236 (0.061)***	-0.345 (0.04)***	-0.193 (0.053)***
S2	0.725 (0.176)***	-0.416 (0.3)		
S4	0.668 (0.22)*	0.300 (0.283)		
Y99	-1.597 (0.232)***	1.185 (0.289)***	-0.047 (0.412)	1.315 (0.339)***
Y00	-1.126 (0.227)***	0.704 (0.332)*		
Number of records	22,555	22,555	9,395	9,395
χ^2 statistic	612 (26 df)		127 (16 df)	
R^2_L	0.180		0.130	

^a Only variables that were significant at 10% level (LR test) during backward elimination procedure are reported. Variables I4, Y98, and S1 in both models were omitted to avoid redundancy. Prior to estimation, variables RSS, RSA, REA, RNA, PHYTOM (*Dianthus* model) and RSS, RSA, REA, and RNA (*Chrysanthemum* model) were removed due to data separation problem. * $P < 0.05$, ** $P < 0.01$, and *** $P < 0.001$.

The results showed that factors representing the income class and agricultural export characteristics of the shipments' countries of origin were statistically insignificant if included in the estimated equations together with geographic variables, due to high intercorrelations. In single-species models, variables for income classes were statistically significant predictors of the likelihood of rejecting shipments when correlated variables were eliminated; the likelihood of rejecting shipments of *Dianthus* due to phytosanitary reasons and of shipments of *Chrysanthemum* due to nonphytosanitary reasons was greater for lower income countries. These results are consistent with the hypothesis that wealthier countries have more resources to devote to phytosanitary control practices. Furthermore, a significant seasonality in the likelihood of rejecting of shipments due to phytosanitary reasons was observed, confirming earlier work (13,20). Fluctuations in pest populations in exporting countries are a plausible explanation of this result. Frey (13) found that seasonality in pest interceptions was related to the intended use of ornamental commodities (e.g., cuttings and potted plants). Although it was not possible to test this finding because the data set did not specify the intended use of ornamental commodities, the results indicate that seasonality can be significant for some ornamental species (*Dianthus*) and not significant for others (*Chrysanthemum*). Furthermore, significant yearly fluctuations in the likelihood of rejecting shipments were found (in the all-species, 4-species, and *Dianthus* models). This finding may reflect both natural fluctuations in the pest populations and also changes in crop protection practices and policies in exporting countries.

The results further suggest that bigger shipments are less likely to be rejected due to the presence of a pest, *ceteris paribus*. This result was robust to the practice of possible splitting of infested shipments to create infested records in the data set (described above). Several reasons may explain this result. For instance, exporters have greater incentive to carefully check and assure the phytosanitary quality of bigger, more valuable, shipments. Also, it may be that commodities that have high phytosanitary quality (e.g., propagating materials [26]) are imported in bigger shipments. This finding may also reflect the difficulty to obtain a random and representative sample from a large shipment, even if officially, tailgate methods of inspection that target only the most accessible units of a shipment (35), are not applied (J. Schans, PPS, *personal communication*). The more clustered a sample that is taken, the smaller is the probability that a pest, if present, is detected (3). The actual reason for lower probability of pest infestation in larger shipments deserves further study. For proper investigation of the probability of rejecting shipments in relation to their size, it is necessary that the size of a shipment is recorded prior to any splitting (if it is to occur). This need, although perhaps obvious from a viewpoint of predicting the probability of rejecting a shipment, must be less obvious to inspecting agencies that value the size of what is actually rejected more than the size of what initially is imported. This finding was communicated to the Dutch PPS.

In all the estimated models, only a few explanatory variables were significantly associated with the likelihood of rejecting shipments due to nonphytosanitary reasons; for example, the regional variables in the model for *Dianthus* and the variable for the shipment size in the 4-species, *Dianthus*, and *Chrysanthemum* models. In part, this may be because a single inspection outcome (i.e., rejection due to nonphytosanitary reasons) combined such different reasons for rejecting shipments as the absence (incomplete/incorrect filling in) of the phytosanitary certificate and rejection on quality grounds. Various factors, currently not included in the estimated models, may be related to likelihoods of rejecting shipments. For example, the absence of a phytosanitary certificate indicates a general problem of organization of export inspection while the low quality of an imported commodity may be related to poor transportation conditions.

The impacts of explanatory variables can be taken into account when designing import inspection schemes. Purely on qualitative grounds, inspection can be more (respectively, less) focused on commodities or shipments that are indicated to have higher (respectively, lower) likelihoods of being rejected. For example, the results of the all-species and 4-species models suggest that the inspection frequency of shipments destined for importers that have a Phytomark certificate can in general be reduced. On the other hand, a lower frequency of inspection of *Chrysanthemum* shipments on the basis of possession of a Phytomark certificate by an importing company would not be justified because the relevant variable was eliminated as being insignificant from the estimated model for *Chrysanthemum*. Furthermore, the inspection can be focused more on Dutch companies that have a large number of imported shipments but a low variety of imported species. Finally, seasonality in the likelihood of rejecting shipments suggests that inspection of (all or specific) ornamental species may be more intensive in autumn and spring and less intensive in other seasons. The results can also be used to directly calculate the probabilities of rejecting shipments on phytosanitary grounds. This can be useful for example in risk assessment models and in models of resource allocation for import inspection (31).

To test the consistency of the results reported in the paper, an all-species version of the MNL model was fitted to the data set of import inspections of ornamental commodities in the Netherlands from 2003 to 2005 (not reported). There were 179,681 observations in this data set, including 1,156 (0.64% of all) cases of rejections due to phytosanitary reasons and 1,177 (0.67% of all) cases of rejection due to nonphytosanitary reasons. The set of explanatory variables was similar to the one used in this study except that variables representing agricultural export characteristics and Phytomark certificate were not specified; furthermore, variables for specific ornamental commodities represented four ornamental species that had the highest rejection rates from 2003 to 2005. In addition, it was possible to specify a variable for the intended use of an ornamental commodity (a cut flower or a noncut flower). The overall model was highly significant ($\chi^2 = 1830$ [44 df], $P < 0.001$). R^2_L was equal to 0.065 which was lower than R^2_L reported in this paper. The reason for low fit was found when the MNL model was fitted to separate data sets of cut flowers and noncut flowers. The R^2_L was equal to 0.038 for a cut flower sample and to 0.091 to a noncut flower sample. Most statistically significant parameters in the 1998 to 2001 model were also significant in the 2003 to 2005 model, although for some parameters (for example, NSPECIES, D1000+) the signs were reversed. Furthermore, the results showed that shipments of cut flowers were, *ceteris paribus* significantly ($P < 0.001$) more likely to be rejected on phytosanitary grounds than shipments of noncut flowers. Combined, these results suggest that the inspection data are prone to fluctuations and thus the MNL needs periodical readjustments to better reflect the fluctuations in the trends of pest interceptions and changes in the economic environment.

The results reported in this paper can serve as a first step toward development of operational decision-support tools for import inspection. Future work could focus on testing and validation of best predictive models that can be introduced into inspection practice. An example from a seemingly unrelated field, the banking industry, can help illustrate the usefulness of such predictive models. In retail banking, logistic regression has been used to develop so called "scorecards" that support banks' product-granting decisions (17). A scorecard, which is embedded in a computerized interface, uses customers' characteristics (e.g., age and income) entered during the application stage to assess the likelihood of a customer defaulting on a product (e.g., a credit card) and gives a concrete decision (i.e., to accept or reject an application). It is relevant to note that banking has been characterized by large volumes of customer applications and relatively

low default rates for some products, which is in parallel to large volumes of import and relatively low rates of pest infestations of some products in import inspections. This example suggests that the potential benefits of logistic regression for use in decision support tools for import inspection warrant further investigation.

This study showed the importance of collecting in inspection databases additional data that can be useful for analyses and prediction of pest interceptions, e.g., data on the intended use of commodities, the size of the imported shipment, and information related to the importing company. Most importantly, inspection databases should include both positive and negative pest interceptions. Only in this case the MNL model can be identified. Yet, until recently, in some countries (e.g., the United States) only positive pest interceptions have been recorded (20).

In summary, this study demonstrated that the MNL model allows estimating the impact of factors that may influence the decisions to inspect or not inspect particular commodities, commodity pathways, or commodity shipments. In this way, the MNL model can support the inspection decisions of the inspecting agencies. The application of MNL or similar models can be considerably facilitated if the inspecting agencies collect the data related to pest interceptions not only for record-keeping purposes but also with the view of using this data for analysis, prediction and management.

ACKNOWLEDGMENTS

We thank the Dutch Plant Protection Service (PPS) for providing the data set for this research, and the Dutch Agricultural Economics Institute for providing the data on a number of explanatory variables. Very useful comments on the manuscript from J. Schans of PPS are highly appreciated. We also thank J. Nyrop (Cornell University) and W. Zhang (Michigan State University) for critically reviewing the manuscript and giving many helpful comments.

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