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A Mathematical Model for the Epidemiological Analysis of Trichinella - Infection in Pigs

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Abstract

Trichinella spp. is one of the most widespread parasite infecting humans, mammals, and birds all over the world. Despite of the efforts made by public health specialists to control and eradicate it, trichinellosis is considered a re-emerging zoonosis in many areas. Romania is recognized as one of the countries with the highest prevalence of trichinellosis in Europe. With respect to Trichinella-infections in pigs, our country accounted 51.5% of all positive findings in 2012, a similar situation as in 2010 and 2011; with an overwhelming majority, these Trichinella-positive findings originated from pigs raised in backyards. This work aimed to set and implement a mathematical model able to predict the future evolution of Trichinella-infection incidence in pigs. Our analysis was based on the data collected between 1997 and 2013 from pigs raised both in controlled (farms) and non-controlled housing conditions (backyards). The implemented mathematical model showed two main lines of prediction related to the evolution of Trichinella-infection incidence, depending on the origin of pigs. For pigs raised in controlled systems (farms), the mathematical models predict a trend toward zero of the incidence in the next period of time (considering that in the last 4 years included in the study (2009-2013), few positive cases were registered). In the case of pigs raised in extensive systems (uncontrolled conditions), the mathematical models generally predict an ascending trend in Trichinella-infections incidence, this trend reflecting the high incidence of Trichinella-infections in pigs raised in backyards in recent years. In conclusion, statistical processing of the parasitological data may provide a useful modality for understanding the biological processes and the interpretation of epidemiological data.

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1. Introduction

*Trichinella* spp. is some of the most widespread parasite infecting people, mammals and birds all over the world. Trichinellosis is considered as re-emerging zoonosis in many areas around the world, representing a concern for public health authorities (Pozio and Zarlenga, 2013).

Although efforts have been made to improve the management and prevention of this potentially lethal disease, Romania is recognized as one of the countries with the highest prevalence of trichinellosis in Europe.

The genus *Trichinella* is included in list A - Annex I of Directive 2003/99/EC of the European Parliament and of the Council, which states the agents that have to be monitored on a mandatory basis. Currently, the official testing is carried out according to Commission Regulation (EC) No. 2075/2005 laying down specific rules on official controls for *Trichinella* in meat, amended by Commission Regulation (EU) No. 216/2014, these rules applying to domestic swine, wild boars, horses, game and any other susceptible animals’ meat. These regulations require that all pig carcasses have to be tested for *Trichinella*, unless the pigs are derived from holdings or regions that meet stated criteria for being regarded as having negligible risk. The aim of these actions is to remove any contaminated meat from the food chain.

Based on previous epidemiological studies, it is well known that the main species involved in transmission of *Trichinella* to humans is the domestic swine (Cosoroabă and Orjanu, 1998; Malakauskas et al., 2007; Tolnai et al., 2014). Generally, this zoonosis can be controlled by preventing parasite transmission at the farm level and by correctly applying standard hygiene measures (Gamble et al., 2000). Previous studies on *Trichinella*-infection incidence in pigs demonstrated that, in Romania, the number of infected pigs raised farms is low, whereas the main danger is represented by pigs raised in backyards (Drăgoi (Nicorescu) et al., 2014).

This work aimed to set and evaluate a mathematical model able to predict the future evolution of *Trichinella*-infection incidence in pigs in Romania. This kind of approach could be useful for public authorities to conduct the control strategies, as well as for small farmers to establish the local measures to be taken. Statistical processing of the parasitological data may provide a useful modality for understanding the biological processes and the interpretation of epidemiological data.

2. Materials and Methods

Reliable epidemiological data collected between 1997 and 2013 from pigs raised both in controlled (farms) and non-controlled housing conditions (backyards) have been statistically processed and interpreted.

*Trichinella*-infection incidence data were provided by official reports of National Sanitary - Veterinary County Laboratories and Institute of Hygiene and Veterinary Public Health from Bucharest. Trichinoscopy was the method used for the identification of *Trichinella* larvae in meat before December 31st, 2009; since January 1st, 2010, according to Commission Regulation (EC) No. 2075/2005, the applied technique was the artificial digestion.

The prediction model was mainly targeted to Romanian territory as a whole, but the fact that *Trichinella*-infection incidence in pigs shows a great geographical heterogeneity was also taken into account. Consequently, the prediction of future evolution of *Trichinella*-infection incidence in pigs raised in backyards was performed both for all Romanian territory and for each of the seven areas, respectively North-West, North-East, South-East, South, Center, South-West and West.

Based on mathematical and biostatistical considerations, a single exponential smoothing applied to time series data was set up and short-term forecast based on simulation models for the period 2014-2016 was established.

Single exponential smoothing method is suitable for forecasting data with no trend or seasonal pattern. It assigns exponentially decreasing weights as the observations get older (Kalekar, 2004):

\[ S_t = \alpha y_{t-1} + (1-\alpha) S_{t-1}, \quad 0 < \alpha \leq 1, \quad t \geq 2 \]  

where the original and smoothed observations at time \( t \) are denoted by \( y_t \) and \( S_t \), respectively. The initial value \( S_1 \) was set to \( y_1 \). The parameter \( \alpha \), called the smoothing constant, determines the weights assigned to the observations in computed smoothed data (Brockwell and Davis, 2002).

The one-step-ahead predicted value for any time \( t+1 \) is based on the current smoothed \( S_t \) value:

\[ P_{t+1} = S_t \]  

(2)
As our experimental data had no obvious trend or seasonal component, there was no clear evidence to suggest that the predicted value is likely to go up, down or stay the same. Thus, forecasts made at time t for further forecast horizons will be the same:

\[ P_{t+1} = P_{t+2} = P_{t+3} = \ldots = S_t \]  

Prediction limits (95% confidence interval) were calculated based on the mean absolute deviation (MAD). MAD measures the accuracy of smoothed data with respect to the original data and expresses the accuracy in the same units as the data. Mean Absolute Percentage Error (MAPE) measures the size of the error in terms of percentage.

The statistical analysis was performed using MATLAB routines. The smoothed parameter \( \alpha \) was selected based upon minimizing the mean squared error (MSD) for the one-step-ahead forecasts.

3. Results and Discussion

Statistical analysis was performed for Trichinella-infections incidence in pigs raised in farms and in households all over Romania, as well as in pigs raised in households depending on the geographical region of Romania. This approach was mainly due to the fact that the incidence of Trichinella infections in pigs raised in farms recorded very small values in recent years (unquantifiable in relation to the data recorded in previous years), or often there were no cases of infection.

The implemented mathematical model showed two main lines of prediction related to the evolution of Trichinella-infection incidence, depending on the origin of pigs.

For pigs raised in controlled systems (farms), the mathematical model showed a trend toward zero of the incidence in the next period of time (considering that in the last 4 years included in the study (2009-2013) few positive cases were registered) (Figure 1).

![Figure 1. Single exponential smoothing (\( \alpha = 0.5 \)) for Trichinella-infections incidence in pigs raised in farms in Romania. Accuracy measure of the new model compared to the original data and three-years ahead forecast along with the 95% confidence interval are displayed. Because the incidence rate can not be negative, only the positive part of prediction interval was graphically represented.](image)

Although prior to this period there were reported noticeable rates of incidence, in the last years the number of Trichinella infections in pigs decreased significantly, probable due to the implemented control measures and the appropriate farm hygiene.

Due to the strong decrease of Trichinella infections in domestic pigs raised in farms correlated with appropriate hygienic behavior in slaughterhouses, consumer’s contamination by ingestion of infected meat becomes unlikely.

In the case of pigs raised in extensive systems - backyards (uncontrolled conditions), the mathematical model showed a slight ascending trend of Trichinella-infections incidence, this trend reflecting the high incidence of Trichinella-infections in pigs raised in backyards in recent years (Figure 2). A possible explanation of this trend is that backyard pigs are often raised with minimal biosecurity measures and are constantly at higher risk of contracting the infection from sylvatic animals (Pozio and Zarlenova, 2005). This ascending trend of Trichinella-infection rate in pigs raised in households, for own consumption, represents a worrying situation as long as the most important source of Trichinella infection for humans remains pork and its related products (FAO/WHO/OIE, 2007).
In North-Western area of Romania, the highest *Trichinella*-infection incidence rate in pigs raised in backyards was observed in 2012, followed by a decrease in the next year. This is the reason why the incidence-rate predicted for 2014-2016 is higher than the incidence recorded in 2013 (Figure 3).

Figure 3. Single exponential smoothing (α=0.7) for *Trichinella*-infections incidence in pigs raised in backyards in North-Western area of Romania. Accuracy measure of the new model compared to the original data is displayed. Three-years ahead forecast along with the 95% confidence interval are also displayed.

A similar pattern of *Trichinella*-infection incidence rate was recorded in the North-Eastern area of Romania, but with a lower incidence-rate level. The infection rate for 2014-2016 is predicted at a higher level compared to 2013, but below the level of 2012, when it was recorded a pick of *Trichinella*-infection incidence in pigs raised in backyards (Figure 4).

The prediction for the South-Eastern area of Romania showed a decrease of *Trichinella*-infection incidence rate, compared to the pick incidence-rate values recorded in 2013 in this area (Figure 5). However, this pick could be the outcome of new outbreaks’ emergence, which would lead to the maintaining of a high number of positive cases.

Nevertheless, the predicted *Trichinella*-infection incidence rate is worrying, as long as it is higher than the mean incidence-rate recorded for all territory of Romania between 1997 and 2013.

In the case of backyard-raised pigs in the Southern area of Romania, it was found an ascending trend in *Trichinella*-infections incidence, this reflecting the high incidence in backyards-raised pigs in this region in recent years, especially in 2012 (Figure 6).
In relation to the future evolution of Trichinella-infection in households-raised pigs in the Central area of Romania, the evolution of Trichinella-infection incidence seems to be stationary, maintaining the trend recorded in the last years (Figure 7).
In South-Western and Western areas of Romania, the mathematical model predicted slight decreases of *Trichinella*-infection incidence rate compared to the last recorded values (2013), but taking into account the great variability of incidence-rates recorded so far, it could be possible to obtain a different level of incidence, ranging in confidence interval limits (Figures 8 and 9).

In addition to the decreasing trend predicted for the next three years in these two areas, it is noticeable the low incidence-rate of positive cases (approximately 10/10,000).

Figure 7. Single exponential smoothing ($\alpha=0.5$) for *Trichinella*-infections incidence in pigs raised in backyards in Central area of Romania. Accuracy measure of the new model compared to the original data is displayed. Three-years ahead forecast along with the 95% confidence interval are also displayed.

Figure 8. Single exponential smoothing ($\alpha=0.8$) for *Trichinella*-infections incidence in pigs raised in backyards in South-Western area of Romania. Accuracy measure of the new model compared to the original data is displayed. Three-years ahead forecast along with the 95% confidence interval are also displayed.

Figure 9. Single exponential smoothing ($\alpha=0.5$) for *Trichinella*-infections incidence in pigs raised in backyards in Western area of Romania. Accuracy measure of the new model compared to the original data is displayed. Three-years ahead forecast along with the 95% confidence interval are also displayed.
In contrast to the incidence of Trichinella-infections in pigs originating from farms, the incidence of Trichinella-infections in pigs raised in households, without control, has recorded in last period a worrying increase. Pronounced increases of Trichinella-infection incidence-rates were recorded in almost all regions of Romania in the last years; these aspects have strongly influenced the forecast. Also, the recorded variability suggests that there are changing trends in Trichinella-infection in pigs in terms of the emergence of new outbreaks. As a result of this high rate of Trichinella-infections in pigs along with a poor sanitary-veterinary control, Romania recorded one of the highest human trichinellosis prevalence in Europe (Cuperlovic et al., 2005; Blaga et al., 2007).

Forecast based on single exponential smoothing is accompanied by a good accuracy only when a short-term prediction is performed (in this case, the prediction for the next year). If the last value of original data (year 2013) is compared to the first forecasted value (year 2014), different trends are noticed depending on the geographical area. For some areas, the mathematical model predicts an increased incidence in 2014, whereas in other areas the incidence rate decreases or remains at about the same level. For the next 2 years of prediction, the model mathematical based on single exponential smoothing repeats the value of 2014. Thus, we can properly state the direction of evolution for the next year (2014); for subsequent years (2015-2016) this aspect can be judged only in terms of prediction interval.

It can be observed that in some areas the width of prediction interval is higher, which indicates a greater variability of the data, a possible explanation being that actions of prevention and control of Trichinella infections in pigs are not systematically and consistently carried out at households level.

4. Conclusions

This paper aimed to set a dynamic mathematical model focused on the future evolution of Trichinella-infections incidence rates in pigs in Romania, based on the available epidemiological background.

Depending on the previously recorded variability degree, the forecast predicted incidence-rates ranging between lower and upper limits of the confidence interval, without claiming to establish the exact value of incidence in the future.

The forecast showed two main lines of prediction related to the evolution of Trichinella-infection incidence rate, depending on the origin of pigs.

In the case of pigs raised in controlled systems (farms), the forecast predicted a trend toward zero of Trichinella-infection incidence in the next period of time.

For pigs raised in extensive, uncontrolled systems (backyards), the mathematical model generally showed an ascending trend of Trichinella-infections incidence.

Serving as a basic mathematical framework for understanding the complex dynamics of Trichinella-infections evolution, this forecast could provide the background for the implementation of appropriate control measures.

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