ORIGINAL ARTICLE

A new method of potato late blight forecasting in the Czech Republic

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Abstract

This study describes a newly developed index for predicting and forecasting the first (and potentially subsequent) timing of fungicide application against late blight in potato crops based on weather variables measured close to the crop. Inputs for index calculation were the following: daily minimum temperature, mean relative air humidity and daily precipitation. The decisive moment in the process of forecasting is the sum of daily index values for the previous 5 days. The index was tested in various localities of the Czech and the Slovak Republics for several years with a relatively high success rate exceeding the accuracy of previously applied strategies – NoBlight and negative prognosis. In comparison to the mentioned methods, the calculated index corresponded very well to long-term wet periods and indicated the first application date correctly. In years with no wet periods (in this case, 2015 and 2017), it allowed postponing the first application and reducing the number of required sprays during the growing season. The method does not depend on determining the emergence date, so it can be presented on the internet without cooperation with specific growers in a given locality, and thus supply information for a wider range of users. With knowledge about crop development and the degree of resistance to late blight of grown varieties, users can subsequently choose a specific fungicide and its application date.

Keywords: comparison using methods, forecasting models, late blight, *Phytophthora infestans*, potato

Introduction

Late blight, caused by *Phytophthora infestans* (Mont.) de Bary, is one of the basic diseases of the potato (*Solanum tuberosum* L.), significantly reducing its yield and impairing its quality. The relationship between the progress of the disease and meteorological conditions has been studied by a number of researchers; a relatively comprehensive overview can be found e.g. in Singh et al. (2013). Most methods rely on determining a certain combination of weather variables, which influence sporangium and zoospore germination and subsequent penetration of host tissues through a penetration peg, resulting in crop infection. Van Everdingen (1926) was one of the first researchers to relate late blight distribution with weather conditions, as referred to in Musil and Pohořelá (1978). Van Everdingen found that late blight distribution had to be preceded by four factors: 1) at least 4 h of dew during the night, 2) night temperatures above 10°C, 3) cloudiness covering more than 80% of the sky the next day and 4) precipitation of more than 0.1 mm after a dewy night. These rules are sometimes called "Dutch rules". Beaumont (1947) replaced direct monitoring in the crops with measurements under standard weather stations. He found that the critical period preceding late blight distribution is defined by the following factors: 1) the mean relative air humidity must be higher than 75% for at least 48 h and 2) minimum temperatures must be higher than 10°C. Smith (1956) set similar criteria for predicting late blight occurrence: 1) relative air humidity must be more than 90% for at least 11 h for two consecutive days and 2) the night temperatures cannot fall below 10°C. For Czech conditions, Pejml (1957) set the following rules: 1) for two consecutive days the mean air humidity must be above 80% on the first day and more than 77% on the following one, 2) the minimum air temperature must be more than 11°C. Forsund's criteria (1983) are also noteworthy, since they define favorable conditions for pathogen development: 1) maximum temperature must be in the range of 17–24°C, 2) minimum temperature must be more than 10°C, 3) relative air humidity must be more than 75% at noon and 4) precipitation must be more than 0.1 mm. These conditions must be fulfilled for two consecutive days.

The above-mentioned rules serve to forecast favorable conditions for late blight development regardless of the phenological development of the plant. The plants need to be in the stage suitable for penetration of infectious fibers into tissues. Under Czech conditions, Hrubý and Čača (1988), and Hrubý (2002) evaluated the success of Blitecast and "negative prognosis" strategies for timely forecast of late blight occurrence. The principle of these strategies consists of evaluating combinations of temperatures and air humidity, and/or precipitation, and assigning them a certain value depending on their severity. Reaching a certain value (18–20 for Blitecast, 130–150 for "negative prognosis") indicates the need for chemical control. These values begin to accumulate at crop emergence, namely 50% crop emergence for Blitecast and 70% for "negative prognosis". A similar comparison was performed by Doležal and Hausvater (2010) for "negative prognosis" between 2006–2010 and by Johnson (2005) for the NoBlight method.

An effort has been made in recent years to compile regression dependence between late blight occurrence and individual weather parameters. Filippov *et al.* (2015) took into account the values of day and night temperatures and five days of precipitation in the Moscow region. Ahmed *et al.* (2016) deduced similar regression dependences in Pakistan, using the values of minimum and maximum temperatures, air humidity, and wind speed as inputs. However, these methods can hardly be transferred to other climatic regions.

In the Czech Republic, late blight has been predicted with the use of the "negative prognosis" method developed by Ullrich and Schrödter (1966) combined with Blitecast strategy with a series of other modifications, while considering the so-called risk localities that can be found on the server of the Central Institute for Supervising and Testing in Agriculture (ÚKZÚZ). The NoBlight method is used in the advisory services of the Potato Research Institute Havlíčkův Brod. Comparing the forecasted first application date and the actual occurrence of late blight over a period of several years and in various localities, it was found that these strategies are not always able to predict late blight risk sufficiently in advance. These systems have the following deficiencies:

1. It is necessary to determine the date of 50 or 70% crop emergence. Growers do not always perform detailed phenological monitoring and, when their fields are far away, they do not always check them every day. The NoBlight method presupposes determining the correct emergence, especially in wetter weather, in which it is necessary to decide, whether accumulated units of severity values occurred prior to the date of emergence or after that. Determining the correct date is also problematic in a situation in which the required percentage of crop emergence has been reached but foliage is subsequently damaged by frost.
2. The methods use strict limits for air humidity, from which severity values are set in dependence on air temperature. Air humidity measurement, especially under ordinary operating conditions, is a relatively problematic variable and the error of capacity sensors with right calibration is in the range of ±3% relative humidity. According to Litschmann *et al.* (2012), a small systematic error in the measured air humidity value can also result in an important shift of forecasting the date.

Based on the analysis of available strategies for late blight forecasting and their comparison with actual occurrence in the crop, we decided to develop a new index, which would better reflect the dependence especially between the first late blight occurrence in the crop and the actual weather conditions.

Materials and Methods

If we take into account most hitherto used methods, the following weather characteristics have a decisive role in the development of potato late blight:

1. High relative air humidity. Its importance lies especially in the fact that it extends the time of free water presence on the leaf surface and thus also the time needed for zoospore release from sporangia and the duration of zoospore germination. High air humidity also prevents zoospores from drying. Ullrich and Schrödter (1966) found a period with air humidity exceeding 90% as a favorable condition for "negative prognosis"; a similar limit is also set for the NoBlight system.
2. Minimum air temperature. The minimum temperature of 10°C is usually understood as a limiting factor restricting the development of the disease.
3. Atmospheric rainfall. Rainfall interception on the leaf surface secures the presence of free water necessary for germination. Several models, e.g. the

NoBlight model, do not require precipitation as inputs, other models do. The method described in the study by Muška and Virgovič (1991) is based only on an evaluation of the sum of precipitation at weekly intervals. The presence of free water on leaves can also be expressed via the variable of leaf wetting, commonly used in fruit growing for forecasting fungal diseases, especially apple scab. In the case of potato late blight, however, this variable is very rarely used in the models. It is usually assumed that once relative air humidity exceeds 90%, water, it causes condensation on plant leaves. In some situations, however, the reality can be dramatically different.

How long the factors favorable for pathogen development take to act is also important. In most cases, the minimum period given is at least two consecutive days.

We have tried to apply the mentioned findings into equations which describe suitable conditions for late blight occurrence:

$$I_i = \begin{cases} 100 + 10(T_{\min_i} - 10) + 2(RH_i - 80) + PREC_i, & PREC_i > 0 \\ 100 + 10(T_{\min_i} - 10) + 2(RH_i - 80)/D_i, & PREC_i = 0 \end{cases} \quad (1)$$

$$I_{\text{total}_i} = \sum_{j-0}^{4} I_{i-j}, \quad (2)$$

where:
I_i – daily index on day i,
I_{total_i} – resulting daily index on day i,
$T_{\min_i}$ – minimum temperature on day i (°C),
RH_i – mean relative air humidity on day i (%),
$PREC_i$ – sum of precipitation on day i (mm),
D_i – the number of days in which $PREC_i = 0$ from the last day with $PREC_i > 0$ to day i.

All weather variables are measured outside potato crops with sensors in a standard location.

In the case of favorable conditions for all variables, the value of daily calculated index is more than 100. The highest values hitherto given (for the period of 1975–2016), were between 250 and 280 for most potato production regions. In these cases, a higher amount of rainfall on a given day had a considerably higher share in the total index value. Simultaneously, the precipitation amount ensures increased soil moisture and thus also higher air humidity directly in the crop, i.e. conditions generally considered favorable for late blight development. In the case of no precipitation on the following days, the index value decreased in an inverse proportion (Equation 1). The requirement for multiday favorable conditions is expressed in Equation 2, where individual daily indexes were counted for the last five days. The resulting I_{total} value thus serves for setting a suitable date for forecasting the application against late blight, and/or tailoring chemical control in the subsequent period. Empirically, comparing I_{total} values and actual late blight occurrence in potato crops results in the following finding: if I_{total} value reaches 600, most recorded cases (after the incubation period expires) show symptoms of potato late blight in the crop.

Table 1. List of localities used for verifying index suitability

Locality	Latitude [°N]	Longitude [°E]	Altitude [m ASL]	Number of processed cases
Chlebovice	49.6605	18.2778	350	1
Lípa u H. Brodu	49.5561	15.5372	500	3
Přerov n.Labem	50.1561	14.8292	190	2
Sedlčánky	50.1637	14.7892	190	1
Valečov	49.6440	15.4965	430	3
Velhartice	49.2651	13.3897	650	1
Žabčice	49.0218	16.6156	180	1

The suitability of the described index was verified in seven localities within the territory of the Czech Republic, including regular and early potato production regions. These regions are listed in Table 1. For years, when late blight was first found, the first application date was determined with the use of the NoBlight model, as defined in the study by Johnson (2005), "negative prognosis" by Ullrich and Schrödter (1966) implemented in the NegFry program (Fry *et al.* 1983) and the described index method.

Results

The calculated courses of resulting values of individual methods based on identical input weather data have been transferred into graphs, including the forecasted first application dates for processed cases of recorded first late blight occurrence. From the forecasted date, the incubation period was calculated using air temperature data based on relations published by Schrödter and Ullrich (1966). If the end of the incubation period at least roughly coincided with the date of the recorded late blight occurrence in a given locality, forecasting was considered correct. This procedure is demonstrated in Figure 1 for the locality in Velhartice in 2016. Full circles indicate the terms of forecasting the first application (and/or further applications for the index method and NegFry). The dates of the first application were set in the following way: 1, 2 and 17 June 2016 for the index method, NoBlight and NegFry, respectively. The actual late blight occurrence in potato crops was recorded on 13 June 2016. The index method and NoBlight system generated successful forecasts sufficiently in advance. The NegFry method was unsuccessful, because it indicated the first spray several days after the recorded occurrence. The dates of subsequent treatments forecasted by the index method coincided fairly well with dates indicated by the NegFry program;

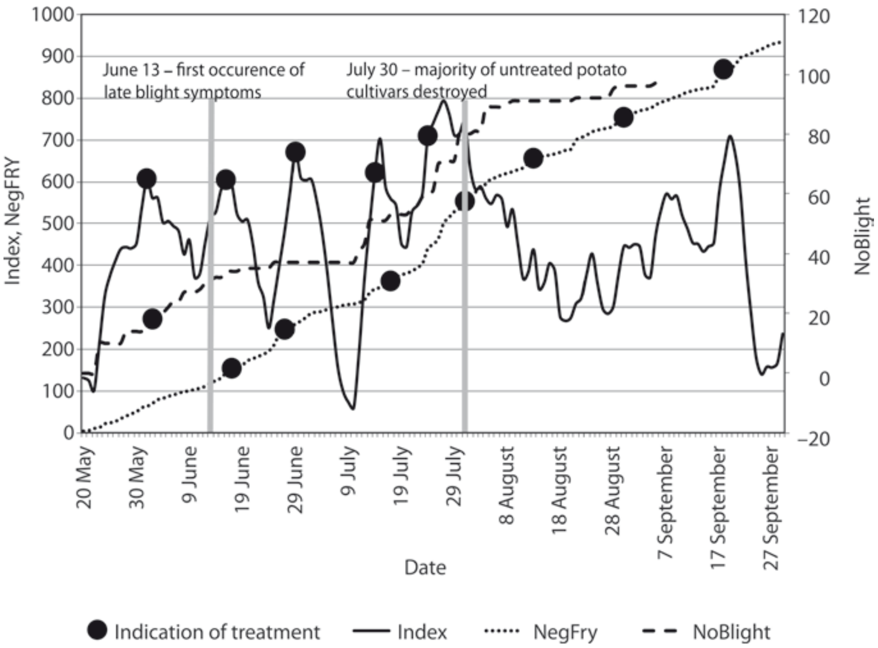

Fig. 1. Comparison of forecasts of first application date using various methods for Velhartice – 2016

this method forecasted two more treatments only in August. A similar evaluation method was also used in other cases and are reviewed in Table 2.

Table 2 shows that in comparison with the other two methods, the success of the index method was substantially higher under the conditions of the Czech Republic; in comparison with the "negative prognosis", the success was almost twofold. A similar success for "negative prognosis", but for another climate region, is given by Pundhir *et al.* (2014).

Due to exceptionally hot and dry weather in 2015, no late blight occurrence was found in any of the studied localities. In the case of the index method, the critical value was exceeded in most of the processed localities towards the end of July and during August, after periods of heavier rainfalls. In the other two methods, the critical value was exceeded earlier, as e.g. in the locality Valečov (Fig. 2). The absence of late blight occurrence, even though the conditions defined in the construction of the index in the second half of the growing season were fulfilled, probably indicates that conditions for pathogen development were not fulfilled in the first half of the growing season, as defined by Muška and Virgovič (1991) in their method which describes the necessity of two wetter periods and infection periods to provide sufficient propagation in May and/or June (for early and medium-early varieties) and in June for late varieties. This theory must be further verified during years unfavorable for pathogen development.

Table 2. Comparison of success for forecasting the first application date by various methods: (+) – forecast successful, (–) – forecast failed

Locality/year	NoBlight	Index	NegFry
Valečov/2009	+	+	
Valečov/2012	–	+	+
Valečov/2013	–	+	–
Chlebovice/2012	–	+	–
Přerov n. L./2013	+	+	–
Přerov n. L./2014	+	+	–
Sedlčánky/2013	+	+	+
Lípa u H. Brodu/2011	–	–	+
Lípa u H. Brodu/2012	–	–	+
Lípa u H. Brodu/2013	–	+	+
Žabčice/2014	+	+	–
Velhartice/2016	+	+	–
Success %	50	83	42

Discussion

The described method of late blight index extends the list of methods used for forecasting potato late blight in the Czech Republic. We can conclude that it is more accurate than the other two widely used methods. In addition, the following advantages can be understood as further benefits, especially in relation to operational practices of potato growers:

1. The method does not require any phenological input data. The index values can be continuously calculated, e.g. from April 1st for early potato production regions, and the growers themselves can decide if the potato crop is sufficiently sensitive to infection after reaching the critical value.

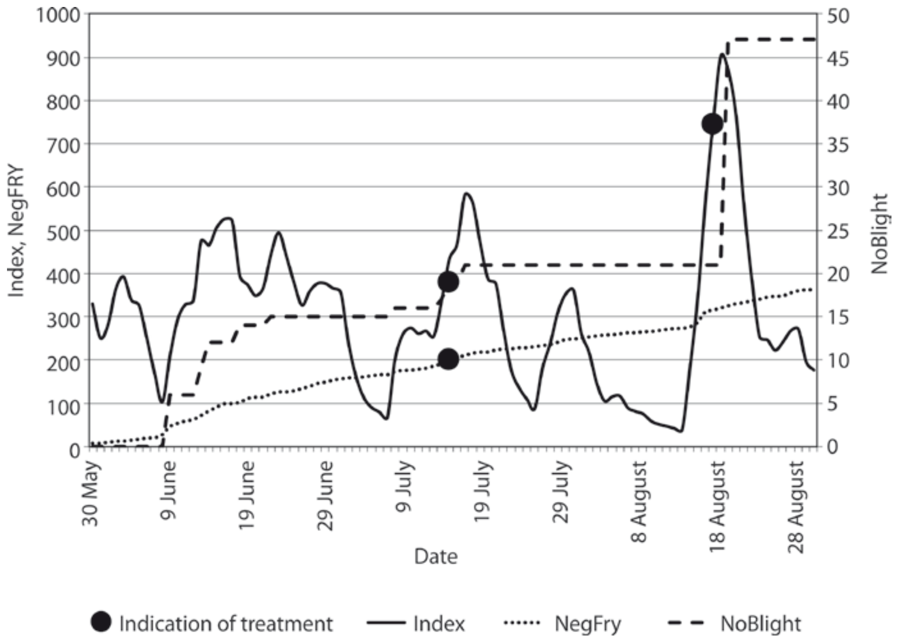

Fig. 2. Comparison of forecasts of first application date using various methods for Valečov – 2015

2. The method uses daily values of weather variables; it is thus also possible to use data manually measured several times a day, without the necessity for automatic recording. In operational practice, it is more suitable to use at least electronic records of temperatures and air humidity and add manual measurement of precipitation. Using only daily data is also suitable for retrospective data processing from previous periods, when continual records of temperature and air humidity are not available.
3. When humidity and air temperature fluctuate around the set limits, the size of the index does not jump dramatically and it changes gradually. A small number of inaccuracies in measurements or differences caused by placing the station outside the monitored crop can thus be eliminated.

While analyzing situations in which the index was more successful, the following causes were found:

1. The sudden occurrence of a long-lasting wetter period. Under favorable synoptic conditions, wet and rainy weather lasts for several consecutive days, during which the conditions for infection development are fulfilled. For the late blight index, the required daily values accumulate after several days and, as a result, the critical value of 600 is exceeded. Similarly, NoBlight is also able to accumulate a sufficient number of critical values during this period defined by prevalent high air humidity and temperature. However, the "negative prognosis" method has only a limited size of maximum daily growth. Especially when wetter periods come shortly after emergence, the critical value is not reached.
2. If a given field is planted later than nearby fields, earlier infection caused by transfer of infection sources from the surroundings can occur in wetter periods for NoBlight and the "negative prognosis" method, accumulating severity values from the emergence date. The index performs continuous calculations, so when a wetter period comes and the crop is emerged enough, infection could occur.

The prevailing influence of long-lasting macroclimatic conditions for the emergence and development of late blight is also referred to by Olanya *et al.* (2007). Iglesias *et al.* (2009) felt that the Smith Periods model provides better results in years with low and medium levels of theoomycete inoculum. The NegFry model is useful to adjust the day of first treatment application, when used together with the Negative Prognosis model.

Based on their findings, a short-time influence of microclimatic conditions by irrigation does not markedly impact the disease. The forecasting methods based on the evaluation of weather variables serve only as supporting information for the grower's decision about relevant measures. It is important to evaluate weather variables in relation to the state of the crop and its susceptibility to infection and/or with the presence of infection sources in a given area. It is important to observe meteorological predictions of the expected weather course. Digital outputs from prediction models for individual localities can be involved in the calculation of the index.

Small *et al.* (2015) stated that in years unfavorable to pathogen development, the use of forecasting methods based on weather data results in substantial savings of applied sprays in comparison to conventional calendar-based applications. Simultaneously, the strain of the crop and the surroundings caused by residues of applied fungicides is reduced as well as the risk of resistance formation in the actual pathogen. In contrast, in years favorable to pathogen development, the number of predicted sprays is increased beyond the usual framework, especially for more susceptible varieties. Gaucher (2007) obtained a saving of 4.5 sprays compared to regular weekly application using Mildi-LIS® in France. We can thus conclude that the described index will supply useful information for potato growers which may allow better optimization of spraying programs.

Conclusions

The analyses performed in several localities in the Czech Republic over an extended period of time indicated that weather conditions certainly play a decisive role in the first late blight occurrence and in further development of the disease. However, there exist several factors modifying the effect of weather conditions in certain cases. It is apparent that in the case of "ordinary" weather conditions, i.e. without major long-lasting wet periods, both methods used around the world, i.e. NoBlight and "negative prognosis", contained in the NegFry program, are capable of predicting the first application date with a certain degree of probability. Nevertheless, it seems that the occurrence of long periods characterized by high amounts of precipitation and air humidity, mainly after a drier period, is more frequent. Presently we are unable to safely state, if this has been a phenomenon of recent years or a common weather expression above the territory of the Czech Republic. Especially the "negative prognosis" is unable to respond to these changes in time: it predicts the application date either shortly before or after the date of late blight occurrence. NoBlight strategy can increase severity value under very wet conditions very fast; however, when significantly wet periods do not occur, the increase is very slow and prediction can come too late. This strategy includes severity values already at temperatures below 10°C which may result in too early predictions in a colder spring.

Both of these methods based on accumulation values from the date of potato emergence in the given locality may in several cases bring non-usable results, especially if a wet period comes shortly after crop cover or if planting is done on a different date than in the surrounding areas and/or on a date that does not correspond to agrotechnical terms in a given region. As far as the NoBlight method is concerned, if a wet period with a high growth in severity value comes around the time of crop emergence, it may be difficult to determine whether this value is included in the calculation or not. This may obviously influence the final result. As regards the operational practices of agricultural enterprises for potato planting on large with more than one variety on different dates, 50 or 70% crop emergence could not be accurately determined and the difference may be several days, especially in the case of cold weather (this is common for wet periods).

The method of late blight index tries to eliminate the mentioned deficiencies. In the case of ordinary weather, it supplies results comparable with the methods of "negative prognosis" and NoBlight strategy. However, particularly in situations with atypical weather, it supplies better results. Since the index does not presuppose that the grower provides any supplemental data on phenological stages of the treated crop and performed cultural measures, it could be done automatically, based solely on data from automated weather stations. Results may be presented either on a website or sent by e-mail to individual growers.

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References

Ahmed N., Khan M.A., Khan N.A., Ali M.A. 2016. Development of predictive model based on epidemiological factors for the management of potato late blight disease. International Journal of Agriculture and Biology 18: 362–369. DOI: 10.17957/IJAB/15.0096

Beaumont A. 1947. The dependence on the weather of the dates of outbreak of potato blight epidemics. Transactions of the British Mycological Society 31 (1): 45–53.

Doležal P., Hausvater E. 2010. Ověření metod prognózy plísně bramboru NoBlight a negativní prognózy v podmínkách České republiky v letech 2006–2010. [Verifying NoBlight and "negative prognosis" methods for forcasting potato late blight in the conditions of the Czech Republic] Vědecké práce – Výzkumný ústav bramborářský Havlíčkův Brod [Academic Papers: Potato Research Institute, Havlíčkův Brod] 18: 23–41. (in Czech, with English summary)

Filippov A., Rogozhin A., Kuznetsova M., Statsyuk N., Ronis A., Platt H.W. 2015. Efficiency of a computerised decision support system as a tool to reduce fungicide input for the control of potato late blight. Zemdirbyste-Agriculture 102 (4): 449–456. DOI: 10.13080/z-a.2015.102.058

Forsund E. 1983. Late blight forecasting in Norway 1957–1980. EPPO Bull 13 (2): 255–258.

Fry W.E., Apple A.E., Bruhn J.A. 1983. Evaluation of potato late blight forecasts modified to incorporate host resistance and fungicide weathering. Phytopathology 73: 1054–1059. DOI: 10.1094/Phyto-73-1054

Gaucher D. 2007. Mildi-LIS®, an online decision support system for treatment against potato late blight. In: "New and Old Pathogens of Potato in Changing Climate" (A. Hannukkala, M. Segerstedt, eds.). Proceedings of the EAPR Pathology Section Seminar, 2–6th of July 2007, Hattula, Finland, 22 pp.

Hrubý R. 2002. Spolehlivost prognóz plísně bramborové. [Reliability of Late Blight Forcasting] Rostlinolékař [Plant Medicine] 13 (4): 22–24.

Hrubý R., Čača Z. 1988. Ověření metody krátkodobé prognózy plísně bramborové [*Phytophthora infestans* (Mont.) de Bary] [Verifying short-time forecasting of potato late blight]. Ochrana rostlin [Plant Protection] (1): 39–45. (in Czech, with English summary)

Iglesias I., Escuredo O., Seijo C., Méndez J. 2009. *Phytophthora infestans* prediction for a potato crop. American Journal of Potato Research 87 (1): 32–40. DOI: 10.1007/s12230-009-9114-y

Johnson S.B. 2005. Late Blight Prediction in Maine. The University of Maine, Cooperative Extension Service, Bulletin 2418, 4 pp.

Litschmann T., Doležal P., Hausvater E. 2012. Citlivostní analýza vybraných modelů na signalizaci plísně bramboru v podmínkách České republiky [Sensitivity analysis of selected methods for forecasting potato late blight in the conditions of the Czech Republic]. Vědecké práce – Výzkumný ústav bramborářský Havlíčkův Brod [Academic Papers Potato Research Institute, Havlíčkův Brod] 20: 133–142. (in Czech, with English summary)

Musil J., Pohořelá M. 1978. Studium možnosti prognózy plísně bramborové na základě meteorologických podmínek. Závěrečná zpráva úkolu [Studying the Possibilities of Forecasting Potato Late Blight on the Basis of Metereological Conditions]. VSUB, Havlíčkův Brod, Czech Republic, 74 pp.

Muška A., Virgovič C. 1991. Metodika krátkodobej prognózy a signalizácie fytoftóry zemiakovej [The Method of Short-Time Forecasting of *Phytophthora infestans*]. Príroda, Bratislava, Slovakia, 150 pp. (in Slovak)

Olanya O.M., Starr G.C., Honeycutt C.W., Griffin T.S., Lambert D.H. 2007. Microclimate and potential for late blight development in irrigated potato. Crop Protection 26: 1412–1421. DOI: 10.1016/j.cropro.2006.12.002

Pejml K. 1957. Předpověď výskytu plísně bramborové (*Phytophthora infestans*, Montagne, de Bary) podle minimální teploty a relativní vlhkosti vzduchu, pozorovaných na meteorologických stanicích. Rostlinná výroba [Forecasting the incidence of *Phytophthora infestans* based on minimal temperatures and relative air humidity, as observed in weather stations]. Plant Cultivation 3 (1): 65–74. (in Czech, with English summary)

Pundhir V.S., Singh B.P., Ahmad I., Kushwaha H.S., Singh V.K., Virendra Joshi 2014. Forecasting late blight of potato in Tarai region of Uttarakhand using modified JHULSACAST model. Potato Journal 41 (2): 95–104.

Schrödter H., Ullrich J. 1966. Weitere Untersuchungen zur Biometeorologie und Epidemiologie von *Phytophthora infestans* (Mont.) de By. Ein neues Konzept zur Lösung des Problems der epidemiologischen Prognose [Further study of biometeorology and epidemiology of *Phytophthora infestans* (Mont.) de By. A new concept to solve the problem of epidemiological prediction]. Journal of Phytopathology 56 (3): 265–278. DOI: 10.1111/j.1439-0434.1966.tb02263.x

Singh V.K., Pundhir V.S. 2013. Forecasting models for potato late blight management – a review. Agricultural Reviews 34 (2): 87–96.

Small I.M., Joseph L., Fry W.E. 2015. Evaluation of the Blight-Pro decision support system for management of potato late blight using computer simulation and field validation. Phytopathology 105 (12): 1545–1554. DOI: 10.1094/PHYTO-05-15-0117-R

Smith L.P. 1956. Potato blight forecasting by 90 per cent humidity criteria. Plant Pathology 5 (3): 83–87.

Ullrich J., Schrödter H. 1966. Das Problem der vorhersage des Auftretens der Kartoffelkrautfäule (*Phytophthora infestans*) und die Möglichkeit seiner Lösung durch eine „Negativprognose" [The problem of potato late blight (*Phytophthora infestans*) prediction and the possibility of its solution using "Negativprognose"]. Nachrichtenblatt des Deutschen Pflanzenschutzdienst 18: 33–40. (in German, with English summary)

van Everdingen E. 1926. Het verban tussende weersgesteldheid en de aardappelziekte (*Phytophthora infestans*). Tijdschrift over Plantenziekten 32: 129–140.