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PRODUCTION OF FRESH SAUSAGES AND OTHER MEAT PRODUCTS
An approach for Fusarium infected corn kernels recognition using linear discrete models

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Abstract. A new approach to identify infected with pink Fusarium maize seeds through the spectral features in the near infrared region is proposed in the paper. It is based on analysis of coefficients of linear parametric models of discrete type Autoregression (AR). Seeds identification criterion is based on the boundary of $A_n$ between the class healthy and class infected seeds. The maximum distance between the two classes - $\Delta A$ for the 10th order of AR-model is used to determine the boundary. The recognition accuracy achieved 100% for a variety XM87/136 and for varieties 26a, Knezha 436 and Rouse 424 the accuracy range was from 97.50 to 98.75%.

Keywords: near infrared spectral characteristics, linear discrete model of the Autoregression type, corn kernels, Fusarium infections

Introduction

Maize diseases are widely spread in all the regions where it is grown and they are one of the most important factors with negative influence on the maize yields. The infectious diseases caused by viruses, fungi and bacteria are significant for the crops, as well as for the production. Infections due to Fusarium spp. are collectively referred to as fusariosis (Denev and Beev, 2002; Beev et al., 2007; Beev, 2009). The pink ear rot is the most popular Fusarium infection (Beev, 2004, 2009). It’s characterised by the appearance of separate or bigger areas of kernels all over the corn cob with white to pink fungal deposits. Most often, the deposits are on the lower part of the maize shucks, at places damaged by insects or when the kernel endosperm is cracked in its upper or lower part. The cause for the pink ear rot are different Fusarium spp. and especially Fusarium moniliforme (Tomov and Jordanov, 1984; Beev, 2009). Infection of ears by Fusarium species can result in mycotoxin development (Denev, 1999, Beev, 2009). Mycotoxin levels in grain vary from year to year and between regions. The key factors comprising likely risk are: preceding crop, crop residues, variety, agronomy and weather at flowering, harvesting and storage (Kirov and Denev, 1990).

When evaluating the quality of agricultural products, not only should certain indicators be controlled, but also the diseased products should be separated from the healthy ones. The quality identification methods could be divided into subjective (organoleptic) and objective (technical, mechanical) methods. The flaws of the subjective methods are mainly the lack of identical perceptions of the different subjects and the instability of perception over time due to tiredness, absent-mindedness, age and other differences. The objective quality identification methods are of physical and chemical nature mainly and they could be defined into the following groups: mechanical, physical, chemical, and electromagnetic (Damyanov, 2006). The methods based on the measuring of electromagnetic radiation (electromagnetic fields, roentgen radiations, radiations in the visible (VIS), ultraviolet (UV) and infrared (IR) areas, laser radiations, etc.) meet the modern requirements of remote and non-destructive quality determination (Damyanov, 2006). Of all of the above methods, the optical ones (UV, VIS, IR) achieve high quality measurement accuracy and correspond very well to the technology conditions and requirements (Damyanov, 2006). Delwiche (2003) identifies wheat kernels infected with mould through spectroscopy of a reflection in the near infrared region. High classification accuracy of 95 per cent is achieved and it is established that the best classification model uses a combination of the grain mass and the difference of the reflection coefficients of the wave lengths – 1182 and 1242 nm. It is established that the most informative wavelengths for a wheat grains sorting machine (for separation of healthy grains and Fusarium spp. infected grains) are achieved through a linear discriminant analysis. 95 per cent accuracy of separation is achieved with wavelength of 500 and 550 nm for the visible region, and 97 per cent accuracy is achieved for the near infrared region with wavelengths of 1152 and 1248 nm (Delwiche and Ganes, 2005). Loos et al. (2005) study the influence of the Fusarium spp. and Microdochium nivale moulds and the formation of mycotoxins connected to them on naturally infected grain seed. Fernandez et al. (2009) offer near infrared spectroscopy as a quick and cheap method for discovery of the toxic matter aflatoxin B$_1$ (AFB$_1$) in maize and barley. The best predictive model to detect AFB$_1$ in maize is obtained by using standard normal variate and detrending (SNVD) as scatter correction. In the case of barley, the best predictive model is developed using SNVD on the dispersive NIRS instrument. There are already algorithms offered for the discovery of Fusariosis infected maize kernels through analysis of their spectral characteristics. The best predictive model is developed using SNVD on the dispersive NIRS instrument. There are already algorithms offered for the discovery of Fusariosis infected maize kernels through analysis of their spectral characteristics on the grounds of their description through linear discrete models of the Autoregression type (Draganova et al., 2003; Mancheva et al., 2009a). Based on the achieved results, an algorithm is offered, which discovers the Fusariosis infected maize kernels through an analysis of the model series and its coefficients. It is established that when the model series is lower than the second, then the kernel is healthy, and when the series is higher than the fifth, it is typical for diseased kernels. In the case of the fourth series of the model, the detection of the diseased kernels is made on the grounds of A2 and A3 coefficients of the model. As the obtained results concern a small number of kernels, this is a prerequisite for the analysis of a set of maize kernels with bigger volume in order to achieve exact coefficients of the AR model. In the procedure for

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evaluation of the characteristics of a set of kernels with bigger volume is repeated (Mancheva et al., 2009a). It is established that the best series for both classes is the ninth series, but this is not a determining factor for identification of the kernels. That is why the coefficients of the models for the both classes of kernels are analysed. A coefficient of the model is used as a criterion for identification, and the other coefficients are commensurable for both classes. The achieved identification accuracy for healthy and diseased kernels is 70 and 80 per cent, respectively (Mancheva et al., 2009a).

The aim of the current study is to choose signs and formulate the criteria for identification of Fusarium infected maize kernels through the introduction of the spectral characteristics of diffuse reflection from the kernels with linear discrete models and the selection of a suitable classification approach. The influence of the kernel variety on the identification accuracy will also be analysed.

Material and methods

The research subject is the pink ear rot infection (Fusarium moniliforme) and its occurrence on maize kernels. Seven varieties of maize kernels were examined – Knezha 308, Knezha 436, Knezha 613, Knezha 620, 26A, XM87/136 and Ruse 424. They have been certified by the Maize Institute in the town of Knezha since year 2008. 700 spectral characteristics of diffuse reflection were taken – 350 of healthy and 350 of diseased maize kernels in the range from 456 to 1140.5 nm. The system for obtaining spectral characteristics of diffuse reflection from the maize kernels is presented in (Mancheva et al., 2009b). USB4000-VIS-NIR spectrophotometer of the Ocean Optics company was used, as well as QR200-7-VIS-NIR probe for measuring the diffuse reflection from the subject surface. The spectral characteristic of each kernel was obtained for its back side and the germ side, pursuant to the methodology described in (Mancheva et al., 2009b). These characteristics show the dependency of the wavelength $\lambda$, nm on the intensity of the reflected radiation from the maize kernels $S_\lambda$, in absolute values. The achieved database with spectral characteristics is shown in (Mancheva et al., 2009b).

Results and discussion

The taken spectral characteristics, shown on Figure 1, are normalized through:

![Figure 1. Regulated spectral characteristics of two varieties of maize kernels](image-url)
The linear discrete model of the Autoregression (AR) type is included 20 spectres of healthy and 20 spectres of diseased maize. The test set includes 30 spectres of healthy and 30 spectres of diseased maize kernels of each kind or totally 210 spectres of healthy and 210 spectres of diseased kernels for all the seven varieties. The test set includes 20 spectres of healthy and 20 spectres of diseased maize kernels of each variety or totally 140 spectres of healthy and 140 spectres of diseased kernels for the seven varieties.

The linear discrete model, describing the spectral characteristics of the healthy class and diseased class of kernels, is analysed. The obtained series of the discrete model of the Autoregression (AR) type is presented in Table 1. The obtained results show that the model series is not a determining indicator for identification of the kernels. Table 1 show that the 10th series of the model is dominating for the seven varieties of maize kernels. That is why only the 10th series will be used in order to receive the coefficients of the model from the training set. Therefore, ten coefficients should be calculated for each variety. Three cases for the A-coefficients of the AR model are obtained and they are shown on Figure 3. In the first two cases, the a) and b) group of the healthy kernels is clearly distinguishable from the group of the diseased objects, the objects are selected so that they are uniformly distributed over the output database. A well-known representative of this approach is the Kennard and Stone Algorithm. In this method, a certain number of objects is defined, which have to be selected from the output ones (Facchin et al. 2005). The obtained spectral characteristics are distributed into two sets. The training set includes 30 spectres of healthy and 30 spectres of diseased maize kernels of each kind or totally 210 spectres of healthy and 210 spectres of diseased kernels for all the seven varieties. The test set includes 20 spectres of healthy and 20 spectres of diseased maize kernels of each variety or totally 140 spectres of healthy and 140 spectres of diseased kernels for the seven varieties.

The n-th series of the linear discrete model, describing the spectral characteristics of the healthy class and diseased class of kernels, is analysed. The obtained series of the discrete model of the Autoregression (AR) type is presented in Table 1. The obtained results show that the model series is not a determining indicator for identification of the kernels. Table 1 show that the 10th series of the model is dominating for the seven varieties of maize kernels. That is why only the 10th series will be used in order to receive the coefficients of the model from the training set. Therefore, ten coefficients should be calculated for each variety. Three cases for the A-coefficients of the AR model are obtained and they are shown on Figure 3. In the first two cases, the a) and b) group of the healthy kernels is clearly distinguishable from the group of the diseased objects, the objects are selected so that they are uniformly distributed over the output database. A well-known representative of this approach is the Kennard and Stone Algorithm. In this method, a certain number of objects is defined, which have to be selected from the output ones (Facchin et al. 2005). The obtained spectral characteristics are distributed into two sets. The training set includes 30 spectres of healthy and 30 spectres of diseased maize kernels of each kind or totally 210 spectres of healthy and 210 spectres of diseased kernels for all the seven varieties. The test set includes 20 spectres of healthy and 20 spectres of diseased maize kernels of each variety or totally 140 spectres of healthy and 140 spectres of diseased kernels for the seven varieties.

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The obtained results show that the accuracy of identification for the other three varieties is lower: for Knezha 620 – 62%, for Knezha 308 – 52.5% and for Knezha 613 – 51.25%.

### Table 1. AR model series describing the normalized spectral characteristics of healthy and diseased kernels

<table>
<thead>
<tr>
<th>Model series n Corn kernels variety</th>
<th>Back side</th>
<th>Germ side</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>healthy</td>
<td>diseased</td>
</tr>
<tr>
<td>Knezha 308</td>
<td>8</td>
<td>6</td>
</tr>
<tr>
<td>Knezha 436</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Knezha 613</td>
<td>8</td>
<td>10</td>
</tr>
<tr>
<td>Knezha 620</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>26 A</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>XM 87/136</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Ruse 424</td>
<td>10</td>
<td>10</td>
</tr>
</tbody>
</table>

### Table 2. The limits $A_{1LV}$ of the model coefficient $A$, between the healthy kernels class and the diseased kernels class

<table>
<thead>
<tr>
<th>variety</th>
<th>Limit $A_{1LV}$ for back side</th>
<th>Limit $A_{1LV}$ for germ side</th>
</tr>
</thead>
<tbody>
<tr>
<td>Knezha 308</td>
<td>- 0.2696</td>
<td>- 0.2788</td>
</tr>
<tr>
<td>Knezha 436</td>
<td>- 0.2168</td>
<td>- 0.2296</td>
</tr>
<tr>
<td>Knezha 613</td>
<td>- 0.2766</td>
<td>- 0.2987</td>
</tr>
<tr>
<td>Knezha 620</td>
<td>- 0.3792</td>
<td>- 0.3915</td>
</tr>
<tr>
<td>26 A</td>
<td>- 0.2895</td>
<td>- 0.3317</td>
</tr>
<tr>
<td>XM 87/136</td>
<td>- 0.2925</td>
<td>- 0.2743</td>
</tr>
<tr>
<td>Ruse 424</td>
<td>- 0.2812</td>
<td>- 0.3038</td>
</tr>
</tbody>
</table>

### Figure 3. Three cases for the A-coefficients of the AR model

#### Table 3. Conditions for classification of maize kernels through the A-coefficients of linear discrete models

<table>
<thead>
<tr>
<th>Variant</th>
<th>Rules</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>a)</td>
<td>If $A_{ij} &gt; A_{ij\text{avg}}$ then corn kernel is healthy, If $A_{ij} &lt; A_{ij\text{avg}}$ then corn kernel is diseased</td>
<td></td>
</tr>
<tr>
<td>b)</td>
<td>If $A_{ij} &gt; A_{ij\text{avg}}$ then corn kernel is diseased, If $A_{ij} &lt; A_{ij\text{avg}}$ then corn kernel is healthy</td>
<td></td>
</tr>
<tr>
<td>c)</td>
<td>If $A_{ij} &gt; A_{ij\text{avg}}$ then corn kernel is healthy, If $A_{ij} &lt; A_{ij\text{avg}}$ then corn kernel is diseased</td>
<td></td>
</tr>
</tbody>
</table>

The test set through the use of the coefficients of the linear discrete models are shown in Table 4.

The obtained results show that the accuracy of identification of diseased kernels of XM87/136 variety is 100 per cent. High accuracy of identification is achieved with the following varieties: Ruse 424 (98.75%), Knezha 436 (97.5%) and 26A (97.5%). The percentage of identification for the other three varieties is lower: for Knezha 620 – 78.75%, for Knezha 308 – 52.5% and for Knezha 613 – 51.25%.
A classifier of the linear discrete model type could be used for identification of healthy and *Fusarium* infected maize kernels for the following varieties: 26A, Knezha 436, XM87/136, and Ruse 424. The accuracy of identification for the Knezha 308, Knezha 613, and Knezha 620 varieties is lower. Other classification procedures should be used for them, in order to obtain higher accuracy of identification. The obtained results show that the variety influences the identification accuracy.

### Conclusion

A classifier of the linear discrete model type could be used for identification of healthy and *Fusarium* infected maize kernels for the following varieties: 26A, Knezha 436, XM87/136, and Ruse 424. The accuracy of identification for the Knezha 308, Knezha 613, and Knezha 620 varieties is lower. Other classification procedures should be used for them, in order to obtain higher accuracy of identification. The obtained results show that the variety influences the identification accuracy.

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