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FIRST STEPS TOWARDS SMART DRYING OF BEEF SLICES SEASONED WITH DIFFERENT PRE-TREATMENTS

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Abstract
In this study, beef slices seasoned with salt (S) and salt and vinegar (S+V) were dried at 60 °C in a convective drier and the development of moisture ratio (MR) and colour change (ΔE) was compared to blind samples (B). Hyperspectral imaging (HSI) was applied to create prediction models for moisture content and L, a and b* values. Regression coefficients of >0.9 could be achieved related to each pre-treatment, but also for combined data of all the pre-treatments.*

Keywords*: beef drying, control system development, hyperspectral imaging, PLSR*

1. Introduction

The demand for dried beef products has increased in recent years since it gained interest as a snack food due to its high protein and low carbohydrate and fat content. Originated in South America as *charqui* and well known as *jerky* from North America, it is gaining more and more interest also in European countries (Research and Markets, 2017).

The organic sector faces several challenges regarding product quality and environmental impact of food processing. The list of chemical components to retain quality attributes is restricted in organic processing, which might require a special focus on the drying process itself to obtain a high quality of the final product and sufficient shelf life.

The idea of product related drying holds possibilities to improve both product quality and environmental impact of processing (Sturm *et al*., 2014). Quality changes in moisture content, colour and other parameters could directly feed back into the process control, which is also known as *smart drying*, enabled by machine learning and computer vision applications that provide high accuracy and efficiency for the food industry (Gunasekaran, 2000, Sturm 2018, Moscetti *et al*., 2018). For the application of a smart drying systems it is essential to monitor the changes inside the product during processing in real-time and non-invasively. Hyperspectral imaging (HSI) presents one technique for non-invasive measurements, which enables 3-D (spatial and spectral) image acquisition and the development of mathematical models, related to the spectral reflectance of a product, to predict quality parameters (Amigo *et al*, 2013, Retz *et al*, 2017, Crichton *et al*., 2017, von Gersdorff *et al*., 2018).

Pre-treatments are essential in meat snack production in terms of enhanced flavour attributes and safety issues. Seasoning can prevent microbial growth, e.g. garlic, or lowering the pH value by using vinegar or other agents (Siripongvutikorn *et al*., 2005). Nevertheless, one of the most effective ways to prevent microbial growth is to significant decrease the water activity of meat products by the addition of salt (Petit *et al*., 2014). However, pre-treatments might influence the spectral properties of products during processing, which might result in challenges regarding the building of generally valid prediction models for non-invasive measurements of quality attributes.

The present study investigated the feasibility of building a generally valid model for determination of chromaticity and moisture content based of hyperspectral data during beef drying for beef samples seasoned with different salt solutions and untreated samples prior to drying.

2. Material and method

For the experiment, frozen roast beef of four 26 month old heifers of the Uckermarker breed was used. After shock freezing two day after slaughter, the beef was stored at -18 °C. After thawing at 2 °C for 18 hours the muscles was sliced with the fiber into slices of 5 mm thickness with an electrical slicer (Graef, Allesschneider Vivo V 20, Arnsberg, Germany) and out of the slices pieces of 50 x 50 mm were cut out with a knife, which resulted in 24 pieces per animal and therefore 8 pieces per pre-treatment.

For the seasoning, two 10 % (m/v) salt solutions were prepared, one water based (S), the second with organic apple vinegar as solvent (S+V). The remaining samples were kept untreated as blind samples (B). The samples were seasoned for 18 hours at 2 °C.

The dehydration was carried out in a hot air dryer at 60°C (HT mini, Innotech Ingenieursgesellschaft mbH, Germany).

The weight was measured with a lab balance (lab scales, E2000D, Sartorius, Göttingen, Germany) and CIELab L, a* and b* values with a Chroma Meter CR-400 (Minolta, Osaka, Japan). Measurements were carried out before seasoning, before and during the drying process. Data was collected on three different points per sample and the average was calculated. The intervals for measurements during drying was every 20 minutes during the first hour of dehydration, every 30 minutes during the second hour and every 60 minutes afterwards. The drying process was stopped after 480 min, since moisture content calculations reached 15 % wet base (wb) after that time. For determination of the final moisture content, the samples were dried in an oven at 105 °C for 24 hours (AOAC, 1990).

The moisture ration (MR) was calculated with the following equation with M as moisture content at any time and M_i as the initial moisture content, simplified according to Rayaguru and Routray (2012):

$$\mathrm{MR} = \frac{\mathrm{M}}{\mathrm{M_i}} \tag{1}$$

The total colour change (ΔE) was calculated with the data from coulour measurements before (*i*) and at every time (*t*):

$$\Delta\mathrm{E} = \sqrt{(\mathrm{L}_i - \mathrm{L}_t)^2 + (\mathrm{a}^*_i - \mathrm{a}^*_t)^2 + (\mathrm{b}^*_i - \mathrm{b}^*_t)^2} \tag{2}$$

Further, the samples were imaged with a hyperspectral camera (ImSpector V10E PFD), which was coupled to a linear translation stage (SPECIM Spectral Imaging Ltd., Finland) in the same time intervals as the weighing and colour measurements. The conveyor belt moved with a speed of 8 mm/s, a 35 mm lens (Xenoplan 1.9/35, Schneider Optische Werke GmbH, Germany) was positioned 27 cm above the tray to enable a spatial area of 0.03 mm^2 per pixel. This set up resulted in the capturing of spectral data of 400-1010 nm in 1.5 nm increments. Three 60 W halogen GU 10 bulbs provided a proper illumination, as white reference a white tile of 200 mm x 40 mm were used. Depending on the conveyor belts size, a dark file and an image file was captured of for four slices, respectively.

The data from the HSI was processed with Matlab software package (MATLAB R2013a). The method is according to Crichton *et al*. (2015). In a first step, the images were pre-processed, which means the estimation of the dark noise by removing the spatial mean signal at each wavelengths of the dark file from the respective image file:

$$MDN_\lambda = \left(\frac{\sum_N I_{DN\lambda}}{N} \right) \tag{3}$$

with MDN_λ as the mean value at the specific wavelength λ of the calculated dark noise (DN), $I_{DN\lambda}$ as the raw DN value at the wavelength at a given pixel, and N as the total number of pixels in the DN file.

In a further step, the beef slices as well as the white reference were detected and segmented automatically from the background. Afterwards, the average illumination (W(λ)) for each column of the image related to the white reference was calculated. This enabled the calculation of the relative reflectance ($R(\lambda_{xy})$) of each pixel in the image on a column by column basis due to the retrieved illumination spectrum for each column with the following equation:

$$R(\lambda_{xy}) = \frac{I(\lambda_{xy}) - MDN_\lambda}{W(\lambda_{xy}) - MDN_\lambda} \tag{4}$$

where W(λxy) is the spatially averaged illumination spectrum and I(λxy) is the irradiance spectrum. Finally, between the segmented images and the newly calculated reflectance images $R(\lambda_{xy})$ a logical AND operator was used to calculate the average reflectance spectra of the beef slices

The relative reflectance was used to build PLSR models with Rstudio software (Rstudio, Inc., 2011) to predict moisture content and colour. The data was randomly split, 70 % was used for model building, 30 % to validate the model, respectively.

3. Results and discussion

The drying curves for beef slices seasoned with different pre-treatments did not differ greatly. However, the seasoning with salt solution led to an increase in drying time (Figure 1 a)), which is in accordance with former results by von Gersdorff *et al*. (2018) for beef slices dried at 70 °C and is explainable by the increased water holding capacity of the beef induced by Na^+ and Cl^- ions in the salt (Desmond, 2006). Regarding the total colour change ΔE (Fig.1 b)), there were significant changes especially at high moisture ratios, which decreased throughout the different pre-treatments at decreasing moisture ratios.

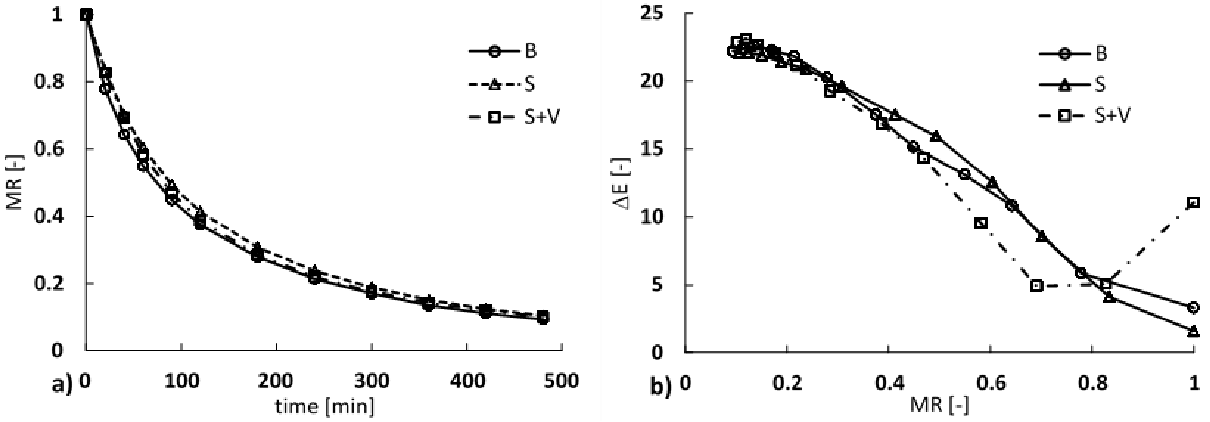

Fig. 1. Drying curves a) and development of total colour change ΔE b) related to MR of beef slices dried at 60 °C untreated (B), dipped in salt solution (S) or dipped in salt and vinegar solution (S+V) before drying.

The values greater than zero of the colour change at the start of the drying process resulted from the seasoning and resting of the samples overnight in comparison to the fresh samples. Especially the samples treated with salt and vinegar showed big changes in L, a* and b* values. While lightness and yellowness increased, the redness decreased after the pre-treatment, which is due to the denaturation of the myoglobin induced by the decreased pH (Trout, 1989), which resulted in the biggest overall change for those samples. For the samples treated with salt solution, the colour was preserved during seasoning, resulting in the smallest ΔE after seasoning, while the blind samples showed increasing L, a* and b* values, expressed in a small ΔE between preparation and during the start of the drying process.

Fig. 2 shows the relative reflectance after seasoning of the beef slices (0 minutes) and after the drying process (480 minutes). For the samples of all pre-treatments the reflectance in the red range region of the visible light is dominant due to the red colour of the beef which is in accordance with Wu & Sun (2013). However, with decreasing moisture contents and therefore increasing darkness of the samples, the expression of the reflectance decreased. The typical O-H stretching overtone expressed in absorption peaks at 760 nm was less expressed for the samples before the drying step than after drying, but was obvious for all samples at 970 nm, indicating the presence of water inside the samples (Wu & Sun, 2013). However, it is obvious, that the pre-treatment influences the reflectance, especially at high moisture content and therefore might impact the building of prediction models based on the reflectance spectra.

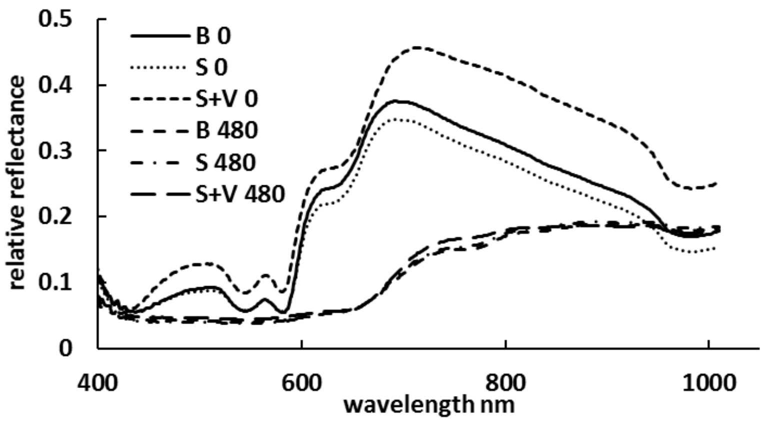

Fig. 2 Relative reflectance of beef dried at 60 °C air temperature after 0 minutes and 480 minutes of dehydration, untreated (B), dipped in salt solution (S) or dipped in salt and vinegar solution (S+V) before drying.

Despite obvious differences in development of colour, the spectral data of the combined data of the three pre-treatments allowed to build a well-fitting PLSR prediction model (Fig 3a) for MC with R^2 = 0.9813 (RMSE = 2.33). Comparably good results were obtained for L (R^2 = 0.9271, RMSE = 1.45), a* (R^2 = 0.9742, RMSE = 1.10) and b* values (R^2 = 0.9682, RMSE = 0.64) (Fig. 3 b)-d)), which indicates a potential for a smart drying system implementation for beef drying independent of the pre-treatment of the beef slices.

Compared to the models build from data of each individual pre-treatment, the corresponding R^2 and RMSE values did not show significant better results. The R^2 for MC prediction with the PLSR models was 0.9911 (RMSE = 1.59) for blind samples, for salt pre-treatment 0.9927 (RMSE = 1.56) and for salt and vinegar pre-treatment 0.9889 (RMSE = 1.87). For the individual models for B, S and S+V observations, R^2 and RMSE indicated very good PLSR models with the lowest R^2 = 0.9341 for L (S).

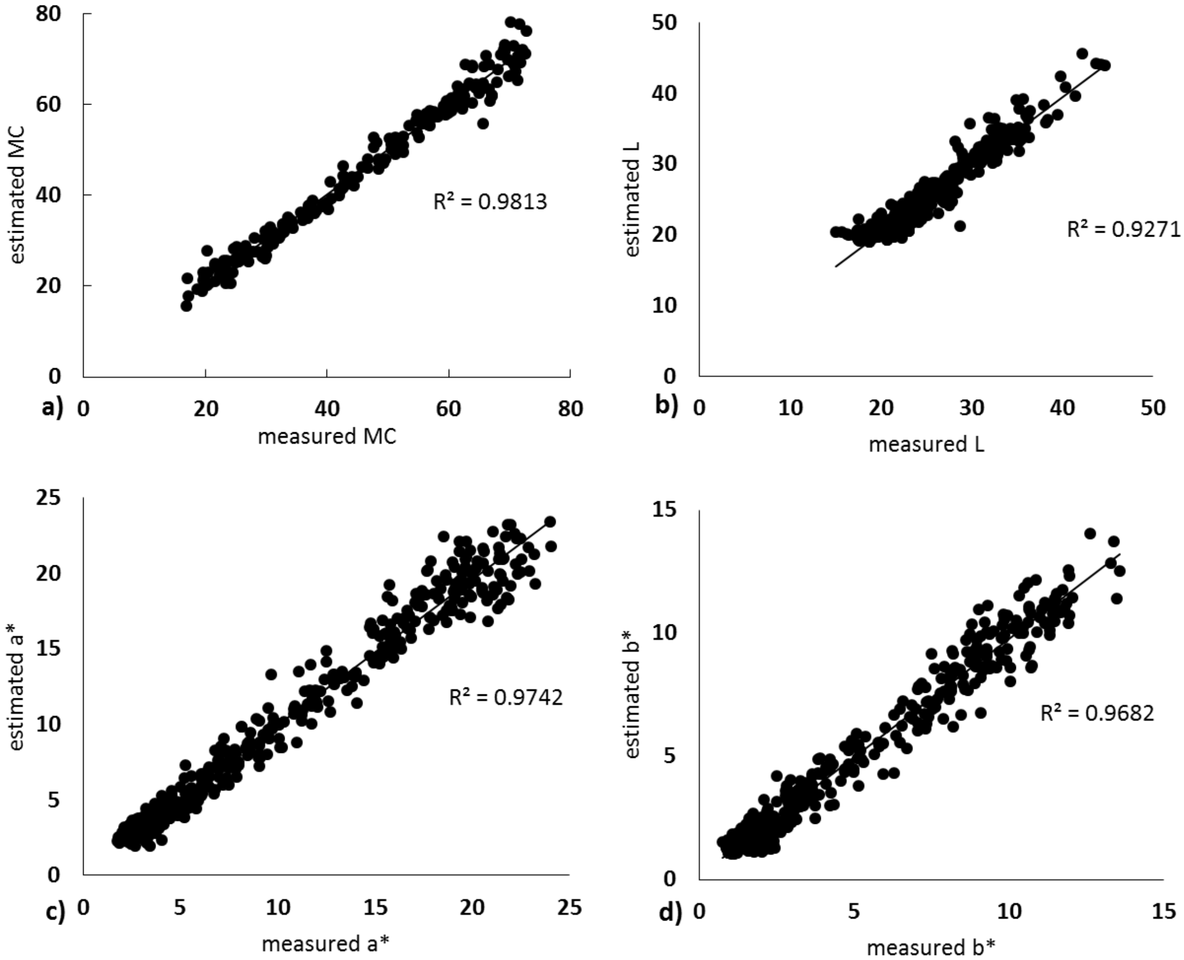

Fig. 3 Measured vs. predicted MC, L-, a- and b*-values for PLSR models build from combined data from beef slices treated with different pre-treatments and dried at 60 °C.*

A next step in terms of prediction models could be the testing of reduced sets of wavelengths for product monitoring and the dependence of relevance of certain wavelengths on different pre-treatments for beef slices. Furthermore, the potential for extension of the prediction model to other muscles should be investigated.

4. Conclusions

The results obtained show the influence pre-treatments can have on drying behaviour and colour development of beef slices during drying. Despite the difference in raw material due to the pre-treatments, the spectral reflectance data allowed to build an accurate PLSR models to predict quality parameters regardless of the pre-treatment. This could enable not only the implementation of smart drying systems, but even the development of easy and cost efficient monitoring systems.

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