biosystems engineering 171 (2018) 193–204

Available online at www.sciencedirect.com

ScienceDirect

journal homepage: www.elsevier.com/locate/issn/15375110

Research Paper

# Predicting poultry meat characteristics using an enhanced multi-target regression method

*Everton J. Santana* [a,*], *Bruna C. Geronimo* [b], *Saulo M. Mastelini* [c], *Rafael H. Carvalho* [b], *Douglas F. Barbin* [d], *Elza I. Ida* [b], *Sylvio Barbon Jr.* [c]

[a] *Department of Electrical Engineering, State University of Londrina (UEL), Rodovia Celso Garcia Cid (PR 445), Km 380, 86057-970, Londrina PR, Brazil*

[b] *Department of Food Science and Technology, State University of Londrina (UEL), Rodovia Celso Garcia Cid (PR 445), Km 380, 86057-970, Londrina PR, Brazil*

[c] *Department of Computer Science, State University of Londrina (UEL), Rodovia Celso Garcia Cid (PR 445), Km 380, 86057-970, Londrina PR, Brazil*

[d] *Department of Food Engineering, University of Campinas (Unicamp), R. Monteiro Lobato, 80, 13083-970, Campinas SP, Brazil*

ARTICLE INFO

*Article history:*
Received 1 March 2018
Received in revised form 24 April 2018
Accepted 30 April 2018

*Keywords:*
NIR spectroscopy
Multi-target
Single-target
Meat quality
Machine learning

Customary methods for assessing poultry meat quality are invasive, generally time-consuming and require specialised analysts. Near-infrared (NIR) spectroscopy represents a powerful alternative with none of these drawbacks. Combining the absorbance for different wavelengths in NIR range with analytical information from reference methods, it is possible to build models for meat quality prediction. These prediction models can be developed independent of each property or based on the statistical dependency of desired extrinsic properties, namely Single-target (ST) or Multi-target (MT), respectively. A new MT method, designated Multi-target Augmented Stacking (MTAS), is compared to the performance of ST and other three MT methods (Stacked Single Target, Ensemble of Regressor Chains and Deep Regressor Stacking) to predict twelve poultry meat characteristics. Different learning algorithms were selected to compose each prediction method: Support Vector Machine (SVM), Random Forest (RF) and Classification and Regression Tree (CART). Results demonstrated that the coefficient of determination was greater than, or equal to, 0.5 for nine out of twelve targets. In addition, the prediction errors were comparable to the error obtained by traditional analysis. Furthermore, MT methods were statistically superior to ST method. In particular, SVM and RF outperformed CART, providing a new tool for identification of poultry meat attributes.



* *Corresponding author.*
E-mail address: evertonsantana@uel.br (E.J. Santana).

https://doi.org/10.1016/j.biosystemseng.2018.04.023

**Nomenclature**

| | |
|---|---|
| $\alpha$ | Significance level |
| $\lambda$ | Number of layers |
| $a^*$ | Redness |
| ARE | Average Relative Error |
| aRMSE | Average Root-Mean-Squared Error |
| aRRMSE | Average Relative Root-Mean-Squared Error |
| $B$ | Base learners set |
| $b^*$ | Yellowness |
| CART | Classification and Regression Tree |
| CD | Critical Difference |
| CIE | Comission Internationale de l'Eclairage |
| CL | Cooking Loss |
| DRS | Deep Regressor Stacking |
| $d$ | Number of targets |
| ERC | Ensemble of Regressor Chains |
| $L^*$ | Lightness |
| $m$ | Number of features |
| ML | Machine Learning |
| MSE | Mean Squared Error |
| MT | Multi-target |
| MTAS | Multi-target Augmented Stacking |
| NIR | Near-infrared |
| PC | Principal component |
| PCA | Principal component analysis |
| $r$ | Regressor |
| $R^2$ | Coefficient of determination |
| RF | Random Forest |
| RMSE | Root-Mean-Squared Error |
| RPT | Relative Performance per Target |
| RRMSE | Relative Root Mean Square Error |
| SF | Shear force |
| SST | Stacked Single-Target |
| ST | Single-target |
| SVM | Support Vector Machine |
| $T^B$ | Targets' prediction set with all base learners |
| U | Measuring unity |
| $W_f$ | Final sample weight |
| $W_i$ | Initial sample weight |
| WHC | Water holding capacity |
| X | Input features set |
| Y | Targets set |
| $Y^F$ | Final targets' prediction set |
| $Y^j$ | j-th layer of targets' prediction set |

## 1. Introduction

The production of poultry meat has rapidly increased in recent years. In 2015, this type of meat was the most produced in the world, achieving a total production of 116.9 million tonnes (FAO, 2017).

Nutritional research in poultry science often requires carcass chemical analysis to assess the nutritive value of meat. Quality of chicken meat is associated to physical and chemical traits usually assessed in the breast muscle. Conventional analysis for moisture, fat, protein and ash are slow-performing, laborious and require the use of chemical reagents and expensive equipment (Cozzolino, Murray, Paterson, & Scaife, 1996).

Traditional analytical methods are usually destructive, requiring lengthy sample preparation procedures. Recently, modern techniques have been investigated for fast, reliable and reagent-less meat quality assessment (Barbin et al., 2015). A good candidate method for the real-time and large-scale estimation of nutritional value is near-infrared spectroscopy (NIR). Wold, Veiseth-Kent, Høst, and Løvland (2017) indicated a regression model for protein and moisture content based on NIR spectra and the estimated concentrations of protein. NIR spectroscopy is based on absorption bands derived from overtones and combinations of fundamental vibrations of chemical bonds observed in the 780–2500 nm range of the electromagnetic spectrum (Porep, Kammerer, & Carle, 2015).

One possibility to predict meat characteristics is to create independent models based on the NIR spectra for each characteristic, a method known as Single-target (ST). This method relies on multivariate linear methods, considered as a branch of Machine Learning (ML) supervised approaches, which are able to automatically detect patterns in the data and use these patterns to predict new data. Recently, some research in different areas has indicated that exploring ML algorithms and taking advantage of the mutual dependence among the outputs (meat properties in this work) could improve prediction accuracy (Aho, Zenko, Dzeroski, & Elomaa, 2012; Borchani, Varando, Bielza, & Larrañaga, 2015; Mastelini, Santana, Cerri, & Barbon, 2017; Melki, Cano, Kecman, & Ventura, 2017; Santana, Mastelini, & Junior, 2017; Spyromitros-Xioufis, Tsoumakas, Groves, & Vlahavas, 2016). These novel methods are known as Multi-target (MT).

This work aims at evaluating MT regression to determine poultry meat characteristics based on the absorbance of the meat for different wavelengths. The NIR spectra was used as predictors for proposing a novel MT method in order to improve the predictive power of this non-destructive, fast and low cost method. A method, designated Multi-target Augmented Stacking (MTAS), is developed by combining the stacking concept with multiple base learners.

This paper is organised as follows: Section 2 discusses the MT regression methods used in the work. Section 3 describes the dataset acquisition, statistical procedures and regression algorithms. Section 4 exposes the results and their analysis followed by Section 5, that concludes the paper.

## 2. Multi-target regression

The customary method to predict continuous outcomes (targets) of a given task is obtaining a separate model for each one of the targets (ST approach). However, the interaction among the outputs could improve their prediction. In this sense, Spyromitros-Xioufis et al. (2016) proposed two MT methods: Stacked Single-Target (SST) and Ensemble of Regressor Chains (ERC).

The SST method, also known as Multi-target Regressor Stacking (MTRS), consists of separately training ST models and using their outputs as additional prediction features. Its representing diagram is available in Fig. 1. Considering a