

Research Article

Recent Advances and Applications of Near Infrared Spectroscopy for Honey Quality Assessment

Guiyun Chen, Yuping Huang and Kunjie Chen

College of Engineering, Nanjing Agricultural University, No. 40, Dianjiangtai Road,
Pukou, Nanjing, Jiangsu 210031, China

Abstract: Currently, most of the technologies used to identify honey quality are inefficient and costly. There is a necessity to develop a more effective one for honey quality assessment. Near Infrared Spectroscopy (NIRS) has the potential to be such a technique for its unique characteristics. This study reviews recent advances and applications of NIR spectroscopy in honey authentication domain including constituents, adulteration, brand, botanical origin and geographical origin. It presents a comprehensive using of this technology, with advantages and limitations, in honey quality detection, which offers insights on selecting the most appropriate NIR spectroscopic method for samples presentation, spectral acquisition, spectral pretreatment and modeling. Future research is to be focused on increasing model robustness, developing overall NIR spectroscopic database and a NIR-based integrated technology system on honey quality assessment.

Keywords: Advances, applications, detection, honey, near infrared spectroscopy

INTRODUCTION

Honey is natural sweet substance produced by bees from nectar of plants and also from honeydew. It is a rich source of readily available sugars, organic acids, various amino acids and in addition rich source of many biologically active compounds. Due to its significant nutritional and medicinal benefits (Ahmed *et al.*, 2007), honey is rather preferred by consumers. Meantime, honey is one of the most seriously adulterated agro-products. It is not an easy task to assess honey quality, for its composition varies with such factors as its botanical and geographical origin, production methods and storage conditions. Traditional chemical composition analysis and physical properties assessment are routinely performed in commercial trading of honey using time-consuming analytical methods that require considerable sample preparation and analytical skills (Cozzolino *et al.*, 2011). As more and more attention is paid to honey quality and safety, various modern testing techniques have been developed including Nuclear Magnetic Resonance (NMR), chromatography, Isotope-Ratio Mass Spectrometry (IRMS), spectroscopy and so on. Each of these techniques has its strengths and weakness, among which NIR spectroscopy is the most attractive and potential technique for its unique characteristics.

Near infrared spectroscopy region (from 780 to 2526 nm) of the electromagnetic spectrum was discovered by William Herschel in 1800. It was first used to analyze chemically complex samples by Karl

Norris in the 1960s. NIR spectroscopy gives spectral fingerprints of organic compounds by measuring combination and overtones of the fundamental O-H, C-H and N-H bonds vibration. This spectroscopic analytical method relies effectively upon spectrometer, chemo-metrics and computer technology. As a result, it was not until the 1990s that NIR spectroscopy was applied in industries ranging from agricultural commodities composition analysis to petrochemical process control and noninvasive medical analysis. While in the food and agricultural industries, it is mainly used to assess quality and authenticity of various food or agro-products such as grains, oilseeds, fruits, honey, coffee and dairy products (Lu, 2007; Wang *et al.*, 2011; Chu *et al.*, 2006). Nowadays, NIR spectroscopy has become one of the most attractive analytical techniques due to its characteristic of being reliable, rapid, nondestructive, low cost and suitable for online use.

The present review is aimed at helping researchers or professionals choose the most appropriate NIR spectroscopic method of samples presentation, spectral acquisition, spectral pretreatment and modeling to test honey quality and also helping them identify the applying trend of NIRS for honey quality assessment so as to improve the application. A comprehensive overview of the use of NIRS in this field is presented, with Web of Science, Elsevier Science Direct and CNKI (China National Knowledge Internet) as literature resources.

Corresponding Author: Kunjie Chen, College of Engineering, Nanjing Agricultural University, No. 40, Dianjiangtai Road, Pukou, Nanjing, Jiangsu 210031, China

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APPLICATIONS OF NIRS METHODS FOR TESTING HONEY QUALITY

NIRS was first used to test honey quality in 1998, when Ha *et al.* (1998) and Cho and Hong (1998) determined respectively honey constituents with NIR spectroscopy. A similar study was conducted by Qiu *et al.* (1999) from Hong Kong. And Hou *et al.* (2007) searched for the feasibility of applying NIRS to the honey quality analysis, which initiated researches in Mainland China. So far, there are around fifty papers on the application of NIRS for honey quality assessment by retrieving data from the above-mentioned databases. These papers cover five different aspects of honey analysis as follows: components and properties determination (sixteen), adulteration identification (thirteen), botanical origin recognition (thirteen), geographical origin verification (five) and brand identification (two).

Components and properties determination:

Approximately one thirds of the papers available are about composition determination and physical or chemical properties assessment by NIRS. All of these researches were carried out with the purpose of exploring the feasibility of using NIRS to analyze honey components and physical or chemical properties. They reached such a conclusion that NIR spectroscopy analysis is in consistency with reference methods on the whole. It can be used to identify most of indicators rapidly and satisfactorily like fructose, glucose, sucrose, maltose, moisture, ash content and ratio of fructose to glucose. However, the prediction values of minor components such as free acid, lactone, some oligosaccharides, Hydroxymethylfurfural (HMF) are not very reliable. Moreover, the results of PH value and electrical conductivity are mostly not ideal as well.

Adulteration identification: There are all together thirteen papers available on honey adulteration identification by NIRS. These researches center on discrimination of the most common adulteration i.e., addition of sugar materials such as high fructose corn syrup (Kelly *et al.*, 2006; Chen *et al.*, 2011), jaggery syrup (Mishra *et al.*, 2010), fructose and glucose mixtures (Downey *et al.*, 2003; Zhu *et al.*, 2010), maltose syrup (Li *et al.*, 2010a). Their results showed that NIRS can be used together with chemo-metrics technology for rapid differentiation of those sugar adulterants in honey and that it is necessary to increase the quantity of representative samples to improve model accuracy and stability for further research.

Botanical origin recognition: The use of NIRS in honey botanical origin recognition is covered by thirteen papers, which indicate that NIRS is a valuable,

rapid and nondestructive tool for the authentication of some honey varieties. For example, NIRS enabled a reliable discrimination of acacia, chestnut and fir honeydew honey from the other unifloral and polyfloral honey types. The error rates ranged from <0.1 to 6.3% depending on the honey type (Ruoff *et al.*, 2006). Acacia, linden, rape, vitex and jujube were classified by and large with correct classification rate of higher than 80% in different NIRS models (Chen *et al.*, 2012). Meantime, the feasibility of combination optical spectroscopy with other techniques such as electronic tongue was also studied for the discrimination of honey floral origin (Ulloa *et al.*, 2013). Obviously, further work with a larger number of samples must be undertaken to confirm the results obtained by these researches.

Geographical origin verification: Honeys produced in a specific region may be preferred by consumers for its unique properties. Consequently such honey is sold at a higher price, which has led to an emerging authenticity problem, i.e., honey geographical origin fraud. Therefore, it is necessary to devise a method to differentiate honeys from different geographical locations. In this respect, five papers reveal that NIRS with chemo-metrics methods has the potential to rapidly identify geographical origin of different honeys. However, translation of this technique into an industrial setting calls for establishment of a large and authentic sample database at significant expense.

Brand identification: The application of NIRS to honey brand identification is covered by only two papers. Shao *et al.* (2008) used Vis/NIR spectroscopy and Artificial Neural Network (ANN) to undertake independent component analysis to develop a nondestructive method for classifying three famous Chinese honey brands with 100% discrimination rate. The same discrimination rate of 100% is obtained by Zhao *et al.* (2011). It is obvious that NIRS and chemo-metrics can also be used for the classification of honey brands. However, very limited samples have been selected by these two papers. As a result, we must be cautious to extrapolate this finding to other honey brands.

APPLICATION OF SPECTRUM COLLECTION TECHNOLOGY

Spectrum collection technology is the first part of NIR spectroscopy technology, which consists of spectrometer selection, sample presentation methods, spectral scanning modes, optical path, time, temperature and so on. The optimization of this technology is an indispensable step for all the application of NIRS to honey detection research.

Ha *et al.* (1998) successfully used both a fixed type and a grating type spectrometer to determine honey components by NIRS. Moreover, Qiu *et al.* (1999) studied the influences of various sample presentation methods on the performance of calibration equations. Samples were scanned with the spectrophotometer in a quartz cuvette with 1, 2, 4 or 10 mm, respectively of optical path length. Reflectance and transmittance spectra were recorded in 2 nm steps. They found that transmittance spectra with 1 mm optical path length produced the best calibration for all constituents examined. Davies *et al.* (2002) measured NIR spectra at five temperatures to explore the possibility of testing the geographical and botanical source of honey by NIRS. In the meantime, in order to explore whether perseitol could be used as a marker for the botanical origin of avocado, Dvash *et al.* (2002) collected reflectance spectra in 2 nm steps after samples were heated to 40°C for 5 min, placed in an optically flat vessel and covered with a 1 mm path length gold diffuse reflector.

Zhang *et al.* (2009) used transreflective integrating sphere mode to collect spectra by 32 successive scans between 4000~10000 cm^{-1} . Its optical path length was 0.1 mm and resolution was 8 cm^{-1} . Tu *et al.* (2009, 2010b) recorded both transreflective spectra (800~2500 nm, 2 mm optical path length) and transmittance spectra (800~1370 nm and 20 mm optical path length) on three different NIR spectrometers (FT, CCD, PDA) to determine honey components. They found that different measuring modes made big difference in prediction accuracy. For glucose, spectra gave better results, whether in short wave region with long optical path or in the entire near-infrared region with short optical path. As for fructose, full spectrum area with short optical path would be better (Chen, 2010) compared in detail the results of four spectra collection modes (transmittance, integrating sphere reflection, fiber optic reflection, transreflectance) at different optical path length, scanning time and temperature. Transreflective fiber optic mode with thirty-two scanning, 5.40 mm optical path length and resolution 8 cm^{-1} at 40°C was believed at last as the best spectral acquisition technique.

It can be concluded that transmittance, reflectance, transreflectance modes all work. Comparatively, transmittance is better than reflectance; transreflectance is the best, thus mostly used and selected by nearly eighteen papers.

APPLICATION OF SPECTRAL PREPROCESSING TECHNOLOGY

Spectral preprocessing technology is the second part of NIRS technology, whose purpose is to extract useful information for subsequent qualitative or quantitative analyses by removing various instrument noises originated from high frequency random noise,

baseline drift, stray light and sample background. This technology generally covers noise filtering (convolution smoothing, multiple scattering correction, Fourier transform, wavelet transform), spectral signal algebraic operation (centralization, normalization, standardization), spectral signal differential, baseline correction and so on (Lu, 2007; Liu, 2008).

Normally, some techniques can be applied to preprocessing honey's NIRS data on many different occasions. For example, smoothing combined with differential, Multiple Scattering Correction (MSC) or Principal Component Analysis (PCA) is believed as a feasible pretreatment method for determining various honey components (Li *et al.*, 2010b), PH (Li *et al.*, 2011a), adulteration (Chen *et al.*, 2008c) and botanical origin (Chen *et al.*, 2009a; Zhao *et al.*, 2011; Liang *et al.*, 2013). PCA and Wavelet Transform (WT) are often used to compress data (Li and Yang, 2012; Davies *et al.*, 2002; Mishra *et al.*, 2010). And WT seems more effective than PCA, as a means for variables selection when processing such complicated high dimensional data set as honey's (Zhu *et al.*, 2010; Li *et al.*, 2011c).

In fact, researchers often select different pretreatments according to the different detection items. Although both MSC and derivative transformation can help to obtain the best classification model (Qiu *et al.*, 1999; Garcia-Alvarez *et al.*, 2000; Dvash *et al.*, 2002; Woodcock *et al.*, 2007, 2009), MSC was found more suitable for adulteration with Beet Invert syrup (BI), while the second derivative transformation was more suitable for adulteration with HFCS in detection of adulteration (Kelly *et al.*, 2006). Besides, Li *et al.* (2010a) and Li *et al.* (2011b) found that the best method for qualitative discrimination was auto-scaling in combination with the first derivative, while for quantitative analysis of adulteration level, the best was center combining first derivative. With regard to detection of geographical origin of honey, Li *et al.* (2011c) pretreated the spectral data with first derivative and auto scaling and then compressed and de-noised them using Wavelet Transform (WT) with satisfactory results. And Herrero *et al.* (2013) used Standard Normal Variate (SNV) transformation as the pretreatment in the study on authentication of honey with Protected Geographical Indication (PGI).

Selection of pretreatment also varies with modeling methods. Chen (2010) found that both of SNV and the first derivative transformation could be mated with Distance Matching method (DM) and convolution smoothing and that the latter could also match Markov Distance Discriminant Analysis (MD-DA). At the same time, their study showed that a derivative, centered and 13 point smoothing was suitable for Discriminant Partial Least Squares (DPLS). Chen *et al.* (2011) selected this pretreatment technique and eight model factors before using DPLS modeling to discriminate authenticity of honey with the correct classification rate of more than 90%.

APPLICATION OF MODELING TECHNOLOGY

NIR spectroscopic modeling technology can be used to undertake qualitative discrimination and quantitative analysis. For qualitative discrimination, it comprises supervised methods (e.g., linear learning machine, discriminant analysis, k-nearest neighbours, soft independent modeling of class analogy, artificial neural network), unsupervised methods (e.g., cluster analysis) and graphic display recognition etc. For quantitative analysis, it is mainly composed of Multiple Linear Regression (MLR), Principal Component Regression (PCR), Partial Least Squares Regression (PLSR), local weight regression, Artificial Neural Network (ANN) (Lu, 2007; Liu, 2008) and Support Vector Machine (SVM) etc.

Application of modeling technology for qualitative classification: Various qualitative modeling techniques were selected to detect honey adulteration. Downey *et al.* (2003) performed Discriminant Partial Least Squares regression (DPLS), k-Nearest Neighbours (k-NN) and Soft Independent Modeling of Class Analogy (SIMCA) to identify authenticity of honey. And DPLS was proved to be the most accurate of these three methods. In Kelly *et al.* (2006) study, SIMCA was used to classify honeys as authentic or adulterated, while PLS regression was used to predict the adulteration level. Mishra *et al.* (2010) successfully developed a model to detect jaggery syrup in honey using PLS regression. Chen (2010), Chen *et al.* (2008c, 2011) and Zhong *et al.* (2010) constructed three models to classify pure honey and adulterated honey samples by DM, MD-DA and DPLS respectively. No significant difference was found among their total correct identification rates. Zhu *et al.* (2010) classified pure and adulterated honey samples using five classification modeling methods including Least Square Support Vector Machine (LS-SVM), Support Vector Machine (SVM), Back Propagation Artificial Neural Network (BP-ANN), Linear Discriminant Analysis (LDA) and KNN. The results showed that the best classification model was achieved by LS-SVM with a total accuracy of 95.1% and WT-LS-SVM could be used as a rapid screening technique for detection of adulteration with fructose and glucose mixtures. Li *et al.* (2010a, 2011b) developed a model for discriminating honey authenticity with the correct identification rate of 100% by PLS-LDA and Competitive Adaptive Reweighted Sampling (CARS). Tu *et al.* (2011) compared the four modeling techniques including PLS-DA, SIMCA, BP-ANN and LS-SVM. They found all the techniques could identify adulterated honey samples well, among which LS-SVM was the best due to the accuracy of 100%.

Qualitative modeling techniques were also applied to identification of honey floral origin and honey brand.

Davies *et al.* (2002) succeeded in characterization of the botanical source of honeys using Canonical Variates Analysis (CVA) and Mahalanobis Distance (MD) calculations. Corbella and Cozzolino (2005) developed classification models using PCA, DPLS regression and LDA. More than 75% of pasture honeys and more than 85% of the *Eucalyptus* spp. honeys were correctly classified by both LDA and DPLS models. And a high accuracy could be achieved when combining PCA with LDA or SVM (Ruoff *et al.*, 2006; Li and Yang, 2012). Chen (2010), Chen *et al.* (2009a, 2012) and Zhong *et al.* (2010) developed three models for discrimination of botanical origin of honey by MD-DA, DPLS and BP-ANN. The performance of nonlinear ANN model was found better than the other two models. BP-ANN was believed suitable for identification of honey floral origin (Liang *et al.*, 2013) and also suitable for honey brands when coupled with independent component analysis (Shao *et al.*, 2008; Zhao *et al.*, 2011). Besides, nonlinear BP-ANN classifier model could significantly improve the accuracy in the case of low feature vector dimension, superior to linear classifier model based on PCA (Yang *et al.*, 2010). Combined with Kernel Principal Component Analysis (KPCA), Tan and Bi (2011) designed a Least Square Support Vector Machine (LSSVM) classification model based on Error Correcting Output Code (ECOC) to distinguish the honey of common and Chinese medicine nectar plant, which ever achieved the accuracy of 96.67%.

In addition, there are a few applications in identification of honey geographical origin. Woodcock *et al.* (2007, 2009) found both SIMCA and PLS gave encouraging results for determining the geographical origin of honey and better correct classification rates were obtained using the latter. In contrast, SIMCA achieved to be the best PGI-model with 93.3% of sensitivity and 100% of specificity amongst the four classification chemo-metric procedures including DPLS, SIMCA, KNN and MLF-NN (Multilayer feed forward neural networks). It was found that KNN and MLF-NN could be adequate for assuring the genuineness of true samples, while SIMCA and DPLS could be more useful for detecting falsifications of true samples (Herrero *et al.*, 2013). Li *et al.* (2011c) established models for classifying honey geographical origin using Radical Basis Function Neural Networks (RBFNN) and PLS-LDA. Their results indicated that the linear WT-PLS-LDA model was more suitable for geographical classification of honey samples than the nonlinear WT-RBFNN model.

Application of modeling technology to quantitative analysis: PLS method was often used to develop honey's quantitative calibration models. Cho and Hong (1998) developed quantitative calibration models of sugars, proline, moisture, HMF, PH, electric conductivity of Acacia honey by this method with

correlation coefficient ranging from 0.84 to 0.98. Similar PLS models were separately built for analysis of sucrose content (Hou *et al.*, 2007), reducing sugars (Zhang *et al.*, 2009), soluble solid and water content, PH and acidity (Li *et al.*, 2010b, 2011a) with satisfactory results except acidity. PLS method can also help to predict adulteration lever of honey adulterated by different concentration of mixture of fructose and glucose syrup (Feng and Luo, 2011), maltose syrup and glucose solution (Li *et al.*, 2010a, 2011b) and so on.

PCR and MLR were also applied to quantitative analyses of honey constituents. Though MLR method was ever found with similar predictive ability in comparison of PLS (Chen *et al.*, 2008a, 2009b; Chen, 2010), the regression model of Modified Partial Least Squares (mPLS) was believed suitable for the calibration of most honey constituents, superior to PLS, PCR and MLR, due to the fact that modification involving standardization of the residues after each iteration can improve stability and accuracy of the PLS calibration (Qiu *et al.*, 1999). Ha *et al.* (1998) and Cozzolino and Corbella (2003) selected mPLS method respectively to predict moisture, PH, electric conductivity, fructose, glucose, sucrose and maltose with relative accuracy result, whereas the prediction for acidity and HMF is not ideal. Besides, accurate prediction equations were successfully developed by mPLS as well, even though average concentration of perseitol in honey samples was only 0.48% (Dvash *et al.*, 2002).

In contrast to linear methods, nonlinear modeling techniques were ever used for quantitative analyses of honey constituents. For reducing sugars, glucose, fructose, two linear models by Backward Interval Partial Least Squares (BiPLS) and Synergy Interval Partial Least Squares (SiPLS) and nonlinear ANN models were developed at the same time. The performance of BiPLS was similar to that of SiPLS, while the performance of non-linear models was better than linear models (Chen *et al.*, 2008a, 2009b; Chen 2010). Compared with linear PLS method, Support Vector Machine (SVM) was used to analyze the non-linear information when building quantitative calibration models for honey constituents such as glucose and fructose. It was found that linear PLS method could obtain good results and non-linear SVM method did not improve the model performance (Tu *et al.*, 2009, 2010b).

CONCLUSION

In a word, NIRS can be applied to the test of honey components, adulteration, botanical and geographical origin and also honey brands. Spectral collecting, spectral pretreatment and modeling technology are the indispensable parts of this technology, among which modeling technology is the core one. Selection of

qualitative modeling techniques generally varies with research content. For adulteration recognition, PLS-DA, SIMCA, BP-ANN and LS-SVM are all effective, among which WT-LS-SVM is the best and PLS-DA may be as the second selection. Linear WT-PLS-LDA is more suitable for geographical origin identification and SIMCA is the most useful for detecting falsifications of genuine PGI honeys. And BP-ANN or LS-SVM is the selection recommended for honey floral origin and brands discrimination. As for quantitative modeling techniques selection, linear modeling methods such as PLS and MLR is workable and mPLS is the best and also most frequently used. The prediction performance of non-linear modeling method ANN is a little better than linear methods, whereas SVM is not as such.

But there are still some defects in present studies. Firstly, the prediction values of PH, acidity, lactone, electric conductivity, HMF, turanose, kojibiose of honey are still unreliable, even though NIRS can accurately identify such major components as glucose, fructose, sucrose and water. Secondly, most adulterated samples in the literature were not collected from market but from laboratory. They cannot reflect various adulterations in reality. Such types as trace adulteration, quality adulteration, bee feeding with sugars cannot currently be identified. Thirdly, water interference with useful information has not yet been resolved technologically. Fourthly, studies on identification of honey brands and geographical origin are far from enough to protect those honey products with high brand value in honey market. Finally, stability and robustness remain to be improved due to deficiency in selecting representative samples.

Naturally, these problems turn out to be the focus of future research. As a result, it is a great necessity to introduce more advanced chemo-metrics methods to build a comprehensive NIR spectroscopic database on honey components, adulteration, botanical and geographical origin and also honey brands. In addition, it is necessary to expand the number and origin of honey samples including the adulterated and unadulterated to increase the robustness of models. Model transfer technology may be introduced to this field as well. Last but not least, the combination of NIR spectroscopic technology with other technologies such as hyper-spectral imaging, electronic tongue (Ulloa *et al.*, 2013), chromatography, mass spectrometry, rheological or thermal analysis need to be studied in order to develop a honey quality evaluation system of integrated technologies.

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REFERENCES

- Ahmed, J., S.T. Prabhu, G.S.V. Raghavan and M. Ngadi, 2007. Physico-chemical, rheological, calorimetric and dielectric behavior of selected Indian honey. *J. Food Eng.*, 79(4): 1207-1213.
- Chen, L.Z., 2010. Study on quality evaluation for honey by near infrared spectroscopy. Ph.D. Thesis, Chinese Academy of Agricultural Sciences, Beijing, China.
- Chen, L.Z., Z.H. Ye and J. Zhao, 2008b. Study on the authenticity of honey using near infrared spectroscopy. *Food Res. Dev.*, 29(2): 103-106.
- Chen, L.Z., J. Zhao, Z.H., Ye and Y.P. Zhong, 2008c. Determination of adulteration in honey using near-infrared spectroscopy. *Spectrosc. Spect. Anal.*, 28(11): 2565-2568.
- Chen, L.Z., Q. Sun, J. Zhao, X.F. Xue, F. Chen and J.P. Huang, 2008a. Study on the fructose content of honey by using fourier transform near-infrared spectroscopy. *Apiculture China*, 59(12): 17-18.
- Chen, L.Z., Q. Sun, Z.H. Ye, J. Zhao, D.H. Han and X.F. Xue, 2009a. Determination of floral origin of honey by near infrared spectroscopy based on artificial neural network. *Food Sci. Technol.*, 34(8): 287-289.
- Chen, L.Z., X.F. Xue, F. Chen, J. Zhao, Z.H. Ye and Y.P. Zhong, 2009b. Prediction analysis of reducing sugar content in honey using fourier transform near-infrared spectroscopy. *Food Sci.*, 30(8): 147-150.
- Chen, L.Z., X. Xue, Z. Ye, J. Zhou, F. Chen and J. Zhao, 2011. Determination of Chinese honey adulterated with high fructose corn syrup by near infrared spectroscopy. *Food Chem.*, 128(4): 1110-1114.
- Chen, L.Z., J.H. Wang, Z.H. Ye, J. Zhao, X. Xue, Y.V. Heyden and Q. Sun, 2012. Classification of Chinese honeys according to their floral origin by near infrared spectroscopy. *Food Chem.*, 135(2): 338-342.
- Cho, H.J. and S.H. Hong, 1998. Acacia honey quality measurement by near infrared spectroscopy. *J. Near Infrared Spec.*, 6: 329.
- Chu, X.L., H.F. Yuan and W.Z. Lu, 2006. Research and applications of near infrared spectroscopy in china in recent years. *Anal. Instrum.*, 2: 1-10.
- Corbella, E. and D. Cozzolino, 2005. The use of visible and near infrared spectroscopy to classify the floral origin of honey samples produced in Uruguay. *J. Near Infrared Spec.*, 13(2): 63-68.
- Cozzolino, D. and E. Corbella, 2003. Determination of honey quality components by near infrared reflectance spectroscopy. *J. Apicult. Res.*, 42(1-2): 16-20.
- Cozzolino, D., E. Corbella and H.E. Smyth, 2011. Quality control of honey using infrared spectroscopy: A review. *Appl. Spectrosc. Rev.*, 46(7): 523-538.
- Davies, A., B. Radovic, T. Fearn and E. Anklam, 2002. A preliminary study on the characterisation of honey by near infrared spectroscopy. *J. Near Infrared Spec.*, 10(2): 121-135.
- Downey, G., V. Fouratier and J.D. Kelly, 2003. Detection of honey adulteration by addition of fructose and glucose using near infrared transmittance spectroscopy. *J. Near Infrared Spec.*, 11(6): 447-456.
- Dvash, L., O. Afik, S. Shafir, A. Schaffer, Y. Yeselson, A. Dag and S. Landau, 2002. Determination by near-infrared spectroscopy of perseitol used as a marker for the botanical origin of avocado (*Persea americana* Mill.) honey. *J. Agr. Food Chem.*, 50(19): 5283-5287.
- Feng, J.Y. and Y. Luo, 2011. Research on the rapid detection method of honey mixed with fructose and glucose syrup. *J. Anhui Agr. Sci.*, 39(14): 8588-8589.
- Garcia-Alvarez, M., J.F. Huidobro, M. Hermida and J.L. Rodriguez-Otero, 2000. Major components of honey analysis by near-infrared transmittance spectroscopy. *J. Agr. Food Chem.*, 48(11): 5154-5158.
- Ha, J., M. Koo and H. Ok, 1998. Determination of the constituents of honey by near infrared spectroscopy. *J. Near Infrared Spec.*, 6: 367.
- Herrero, C., R.M. Peña, S. Garcia-Martin and J. Barciela, 2013. A fast chemo metric procedure based on NIR data for authentication of honey with protected geographical indication. *Food Chem.*, 141(4): 3559-3565.
- Hou, R.L. Y.L. Cheng and T.H.M. Chong, 2007. Study on the analysis of sucrose content in honey by using near infrared transmittance spectroscopy. *Food Ind.*, 2: 57-58.
- Kelly, J.D., C. Petisco and G. Downey, 2006. Potential of near infrared transmittance spectroscopy to detect adulteration of Irish honey by beet invert syrup and high fructose corn syrup. *J. Near Infrared Spec.*, 14(2): 139-146.
- Li, Y. and H.Q. Yang, 2012. Honey discrimination using visible and near-infrared spectroscopy. *ISRN Spectrosc.*, 2012: 1-4.
- Li, S.F., Y. Shan, X.R. Zhu and G.Y. Li, 2010a. Detection of honey adulteration by addition of maltose syrup using near-infrared transmittance spectroscopy. *Food Sci. Technol.*, 35(12): 299-303.
- Li, S.F., X. Zhang, Y. Shan and Z.H. Li, 2010b. Prediction analysis of soluble solids content and moisture in honey by near infrared spectroscopy. *Spectrosc. Spect. Anal.*, 30(9): 2377-2380.
- Li, S.F., Y. Shan, X.R. Zhu and Z.H. Li, 2011c. Detection of geographical origin of honey using near-infrared spectroscopy and chemometrics. *T. CSAE*, 27(8): 350-354.

- Li, S.F., Y. Shan, W. Fan, Y. Yin, Z. Zhou and G.Y. Li, 2011a. Analysis of pH and acidity of honey by near infrared spectroscopy based on MCCV outlier detection and CARS variable selection. *Food Sci.*, 32(8): 182-185.
- Li, S.F., Y. Shan, X. Zhang, X.R. Zhu and G.Y. Li, 2011b. Analysis of honey adulterated with glucose solution near infrared spectroscopy. *Food Res. Dev.*, 32(5): 114-119.
- Liang, X.Y., X.Y. Li and W.J. Wu, 2013. Classification of floral origins of honey by NIR and chemometrics. *Adv. Mater. Res.*, 605: 905-909.
- Liu, J.X., 2008. *Practical Technology of Near Infrared Spectroscopy*. Science Press, Beijing, China, pp: 98-99.
- Lu, W.Z., 2007. *Modern Near Infrared Spectroscopy Technology*. 2nd Edn., Petrochemical Press, Beijing, China.
- Mishra, S., U. Kamboj, H. Kaur and P. Kapur, 2010. Detection of jaggery syrup in honey using near-infrared spectroscopy. *Int. J. Food Sci. Nutr.*, 61(3): 306-315.
- Qiu, P.Y., H.B. Ding, Y.K. Tang and R.J. Xu, 1999. Determination of chemical composition of commercial honey by near-infrared spectroscopy. *J. Agr. Food Chem.*, 47(7): 2760-2765.
- Ruoff, K., W. Luginbühl, S. Bogdanov, J.O. Bosset, B. Estermann, T. Ziolko and R. Amadó, 2006. Authentication of the botanical origin of honey by near-infrared spectroscopy. *J. Agr. Food Chem.*, 54(18): 6867-6872.
- Shao, Y.N., Y. He and Y.D. Bao, 2008. Application of visible/near infrared spectroscopy to discriminating honey brands based on independent component analysis and BP neural network. *Spectrosc. Spect. Anal.*, 28(3): 602-604.
- Tan, A.L. and W.H. Bi, 2011. Identification of honey by NIR spectroscopy technology based on KPCA and LSSVM. *Laser Infrared*, 41(12): 1331-1335.
- Tu, Z.H., D.Z. Zhu, B.P. Ji, H.Q. Chen and Z.S. Qing, 2011. Adulteration detection of honey based on near-infrared spectroscopy. *T. CSAE*, 27(11): 382-387.
- Tu, Z.H., B.P. Ji, C.Y. Meng, D.Z. Zhu, L.G. Wang and Z.S. Qing, 2009. Possibilities of near-infrared spectroscopy for the assessment of principle components in honey. *Spectrosc. Spect. Anal.*, 29(12): 3291-3294.
- Tu, Z.H., D.Z. Zhu, B.P. Ji, C.Y. Meng, L.G. Wang and Z.S. Qing, 2010b. Difference analysis and optimization study for determination of fructose and glucose by near infrared spectroscopy. *Chinese J. Anal. Chem.*, 38(1): 45-50.
- Ulloa, P. A., R. Guerra, A.M. Cavaco, A.M. Rosa da Costa, A.C. Figueira and A.F. Brigas, 2013. Determination of the botanical origin of honey by sensor fusion of impedance e-tongue and optical spectroscopy. *Comput. Electron. Agric.*, 94: 1-11.
- Wang, X.Y., X.C. Wang, Y. Liu and Y. Lu, 2011. Application of near-infrared spectroscopy in food adulteration detection: A review. *Food Sci.*, 32(1): 265-269.
- Woodcock, T., G. Downey and C.P. O'Donnell, 2009. Near infrared spectral fingerprinting for confirmation of claimed PDO provenance of honey. *Food Chem.*, 114(2): 742-746.
- Woodcock, T., G. Downey, J.D. Kelly and C. O'Donnell, 2007. Geographical classification of honey samples by near-infrared spectroscopy: A feasibility study. *J. Agr. Food Chem.*, 55(22): 9128-9134.
- Yang, Y., P.C. Nie, H.Q. Yang and Y. He, 2010. Rapid recognition method of nectar plant based on visible-near infrared spectroscopy. *T. CSAE*, 26(3): 238-242.
- Zhang, X., Y. Shan and S.F. Li, 2009. Near-infrared determination of reducing sugar content in honey based on Multiplicative Scatter Correction Partial Least Square (MSC/PLS) method. *Food Mach.*, 25(6): 109-112.
- Zhao, X., Y. He and Y.D. Bao, 2011. Non-destructive identification of the botanical origin of Chinese honey using visible/short wave-near infrared spectroscopy. *Sensor Lett.*, 9(3): 1055-1061.
- Zhong, Y.P., Z.S. Zhong, L.Z. Chen, Z.H. Ye and J. Zhao, 2010. Qualitative identification of floral origin and adulteration of honey by Near-infrared spectroscopy. *Modern Food Sci. Technol.*, 26(11): 1280-1282.
- Zhu, X., S. Li, Y. Shan, Z. Zhang, G. Li, D. Su and F. Liu, 2010. Detection of adulterants such as sweeteners materials in honey using near-infrared spectroscopy and chemometrics. *J. Food Eng.*, 101(1): 92-97.