Near Infrared Spectroscopy: a substitute technology over chemical analysis techniques : A review for food industries

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***Abstract*— This paper focuses on potential capacity of Near Infrared Spectroscopy as an online real time component analysis techniques over conventional chemical analysis techniques. The acceptance of Near Infrared techniques in various fields has been discussed.**

Keywords— A**STM, GMO, Kjeldah, NIR, transflectance.**

I. INTRODUCTION

The recent development in instrumentation has supported the extensive penetration of Near Infra Red (NIR) Spectroscopy and imaging. NIR Spectroscopy is a fast and nondestructive analytical technique that provides chemical and physical information of any complex mixture. Using multivariate analysis, both quantitative and qualitative analysis could be done in no time. NIR spectroscopy has been gaining wide acceptance in varieties of applications like Food and Drug Industries, Petroleum, Pharmaceutics, agriculture and many more.

II. MOTIVATION FOR FOOD GRAIN ANALYSIS

Food producing industries are always interested in quality assurance across the supply chain. Globalization and rising competitiveness forces producers to take strategic action for quality control and product optimization. Quality control and quality assurance are typically performed using classical chemical methods. Such methods usually take considerable time to produce results and involve utilization of harmful chemicals. Consequently, the results are not obtained quickly enough to meet the needs of Operations. Modern analysis techniques and software can provide an even better inside view into your raw materials and products within no time almost as if online.

Food composition databases provide detailed information on the concentrations of nutrients and nutritionally important components in foods. Calculating the nutrients facts from each its ingredient and its percentage is a need of food industry so crop yield would earn well for farmers as well as end users. The development of new and increasingly sophisticated techniques for the authentication of food products continues apace with increasing consumer awareness of food safety and authenticity issues. Food authentication is also of concern to food processors that do not wish to be subjected to unfair competition from unscrupulous processors who would gain an economic advantage from the misrepresentation of the food they are selling.

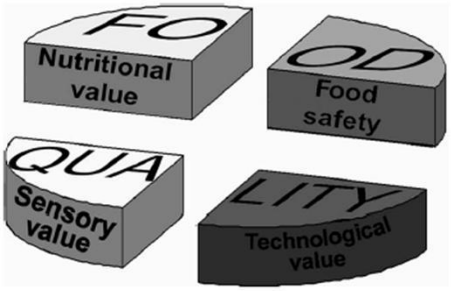

Fig.1. Factors influencing food quality

It is most important to also know the biological values of the food in terms of its sensory values like Genetically Modified Organism **(GMO)**. The need of knowing the GMO values are felt and being researched in most agriculture universities. Considering all such aspect, various techniques for the analysis of food are gaining significance presently.

III. CONVENTIONAL TECHNIQUES OF FOOD ANALYSIS

The conventional techniques adopted for food content analysis like fat, protein etc. are standard chemical techniques developed and approved globally. Table-1 reflects standard tests adopted for some of the food constituents.

Table-1 : Recommended chemical tests for food

Parameter	**Method**	**Reference**
Protein	**Kjeldah**	*Association of American Cereals and Chemists (AACC)*
Parameter	**Method**	**Reference**
Oil	**Single stage air oven**	*AACC*

Moisture	**Goldfisch Extraction**	*AACC*
Crude fiber	**Extraction**	*AACC*

The important test for Protein which is approved is Kjeldah test which is comprised of three stages like Digestion, Distillation and Titration. The N-H bonds in protein by use of Sulphuric acid are broken and converted into ammonia (NH_3) and which in turn by means of a distillation process is separated from liquid phase. Titration is used to find the concentration of Protein in the sample. As the test itself is comprised of unit operation and process, it consumes time to deliver the results and a tedious process too. Hence in cases where online analysis is must, NIR is the only solution has been popularly accepted for food analysis.

IV. Historical Background

Near Infrared radiation was discovered by Friedrich Wilhelm Herschel in 1800 (Davies, 2000) and covers by definition wavelength range from 780 to 2500 nm. When radiation hits a sample, the incident radiation may be reflected, absorbed or transmitted, and the relative contribution of each phenomenon depends on the chemical constitution and physical parameters of the sample.

Although ***Herschel*** discovered light in the Near Infrared (NIR) region as early as 1800, even spectroscopy of the first half of the last century ignored it in the belief that it lacked analytical interest. The Earliest application of NIR was reported in the 1950s, but it was not until the 1970s that the group headed by ***Noriss*** used it to analyze agricultural food samples. The development of equipment featuring improved electronic and optical components and the advent of computers capable of effectively processing the information contained in NIR spectra facilitated the expansion of this technique in an increasing number of fields [15].

The literature reflects the changes in the potential and the appreciation of NIR spectroscopy. Thus Wetzel in 1983 deemed it a "Sleeper among Spectroscopic Techniques" on account of high potential with scan use[14]. McLure in 1994 published a paper entitled "The giant is running strong" because of its increasing number of applications in different field. Davies in 1998, putting forward future possible advances and applications, aptly described its potential as taking it "from sleeping technique to the morning star of Spectroscopy"[7].

The interest in NIR spectroscopy lies in its advantages over alternative instrumental techniques. Thus it can record spectra for solids and liquid samples without any pretreatment, implement continuous methodologies, provide spectra quickly and predict physical and chemical parameters from a single spectrum. These attributes make it especially attractive for straightforward, speedy characterization of samples.

V. Basic Principle of NIR Spectroscopy

The American society of Testing and Materials **ASTM** defines the NIR region of Electromagnetic spectrum as the wavelength range of 780 to 2500 nm corresponding to the wave number range 12820-4000 cm^{-1}. The most prominent absorption bands occurring in the NIR region are related to *overtones* and combinations of fundamental vibrations of -CH , -NH, -OH (and -SH) functional groups. Fig-2 shows the NIR spectrum and chemical composition response at effective wavelengths.

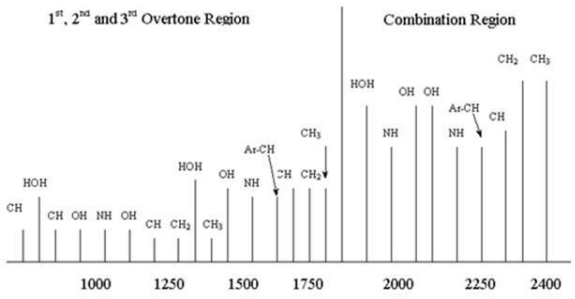

Fig-2 Constituent response at wavelength

The light in NIR band when irradiated on a sample under inspection, following three NIR absorbance phenomenons take place.

Transmission

As has been clear from the Fig-3, the light in the NIR range falls from the source onto the sample and while passing through the sample, the sample depending on its constituents will absorb wavelength specific light which upon measurement from other side of the source will give result analysis. It is related to 1100 - 1800 nm wavelengths and used for high water content samples.

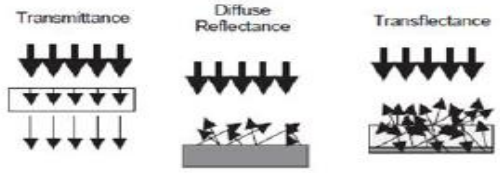

Fig-3 transmittance, reflectance and transmittance

Reflectance

In case of these phenomena, the light returned back due to the reflective properties of the sample would be measured for prediction of sample analysis. This phenomena covers 1800 - 2500 nm wavelength and used for earth samples and solids analysis.

Transflectance

A Transflectance phenomenon is the combination of Transmission and Reflectance as clear from the figure. Hence

reflected as well as transmitted light from the sample will be used for sample analysis predictions. Transflectance occurs in 800 - 1100 nm wavelength and used for slurries, grains and thick sample analysis.

VI. Advantages of NIR spectroscopy

- ✓ It is a non-invasive, non-destructive technique.
- ✓ It requires minimal or no sample preparation. Solid samples can be directly measured with the little pretreatment, or no pretreatment, if an appropriate device is used.
- ✓ Measurement and result delivery are quite fast almost online. Dramatic developments in NIR equipment and chemo metrics used in conjunction with computers have enabled the real time extraction of analytical information from sample.
- ✓ There is no need for reagents or materials to prepare samples and the automation of technique results in increased throughput, which in turn, reduces analytical costs and decreases amortization time.
- ✓ A single spectrum allows several analytes to be determined simultaneously.
- ✓ The technique allows determination of Non-chemical (physical) parameters. In fact, the influence of some parameters on NIR spectrum allows the ready determination of properties such as density, viscosity pr particle size.
- ✓ Because of great strength of optical materials and robustness of NIR equipment, which in most cases has no moving parts, NIR instrumentation is most suitable for use in process control at production level.
- ✓ Fiber optics provides robust, strong sensors for at-line, on-line and in-line analysis to control processes.
- ✓ NIR spectroscopic results are comparable in accuracy to those of other analytical techniques, also, their precision is usually higher, because there is no need for sample treatment.

VII. Disadvantages of NIR spectroscopy

- ✓ NIR measurements are scarcely selective so chemometrics techniques have to be used to model data from which to extract relevant information.
- ✓ There are no accurate models to take account of the interaction between NIR light and matter. As a result, calibration is purely empirical in many cases.
- ✓ Accurate, robust calibration models are difficult to obtain as their construction entails using a large enough number of samples to encompass all variations in physical and/or chemical properties.
- ✓ The need to incorporate the physical and chemical variability of samples in calibration entails using as many as different calibration models as there are sample types, and hence more than one model per analyte.
- ✓ The technique is not very sensitive, so usually it can be applied only to major components.
- ✓ The NIR spectroscopy is a relative methodology, to construct models using it requires prior knowledge of the value for the target parameter, which must be previously, determined using a reference component.
- ✓ The construction of NIR models requires substantial investment, which can, however, be amortized by transferring calibrations from the master equipment to several slaves [15].

VIII. Current trends in NIR research

The use of near infrared spectroscopy has gained momentum and has been used to determine ripping time, probable crop yield time of vegetable/fruit etc. The biggest edge of NIR spectroscopy over conventional chemical techniques is the almost online result. Most research area of interest is the medicine and agriculture field. The publications recently published have increased significantly suggesting the approval of NIR spectroscopic analysis.

References

1. Near Infrared Technology in the agriculture and food Industries, Phil Williams and Karl Norris, Published by : American Association of Cereal Chemist, Inc., USA.
2. Absorption Spectroscopy
3. Abebe, S. B.; Wang, X. Z.; Li, R.; Roberts, K. J. & Lai, X.: The information content in NIR spectral data for slurries of organic crystals. In: *Powder Technology* 179 (2008), Nr. 3, S. 176 – 183
4. Aernouts, B.; Polshin, E.; Lammertyn, J. & Saeys, W.: Visible and near-infrared spectroscopic analysis of raw milk for cow health monitoring: Reflectance or transmittance?. In: *Journal of Dairy Science* 94 (2011), Nr. 11, S. 5315 – 5329
5. Alessandrini, L.; Romani, S.; Pinnavaia, G. & Rosa, M. D.: Near infrared spectroscopy: An analytical tool to predict coffee roasting degree. In: *Analytica Chimica Acta* 625 (2008), Nr. 1, S. 95 – 102
6. Allais, I.; Edoura-Gaena, R.-B. & Ã‰ric Dufour: Characterisation of lady finger batters and biscuits by fluorescence spectroscopyâ€"Relation with density, color and texture. In: *Journal of Food Engineering* 77 (2006), Nr. 4, S. 896 – 909
7. Allen, T. J. & Beard, P. C.: Photoacoustic characterisation of vascular tissue at NIR wavelengths.,
8. Andersson, M.; Svensson, O.; Folestad, S.; Josefson, M. & Wahlund, K.-G.: NIR spectroscopy on moving solids using a scanning grating spectrometerâ€"impact on multivariate process analysis. In: *Chemometrics and Intelligent Laboratory Systems* 75 (2005), Nr. 1, S. 1 – 11
9. AŒurda, L. & KukaÄ?kovÃ¡, O.: NIR spectroscopy: a useful tool for rapid monitoring of processed cheeses manufacture. In: *Journal of Food Engineering* 61 (2004), Nr. 4, S. 557 – 560
10. Balabin, R. M.; Safieva, R. Z. & Lomakina, E. I.: Gasoline

classification using near infrared (NIR) spectroscopy data: Comparison of multivariate techniques. In: *Analytica Chimica Acta* 671 (2010), Nr. 1-2, S. 27 – 35

11. BAO, J.; SHEN, Y. & JIN, L.: Determination of thermal and retrogradation properties of rice starch using near-infrared spectroscopy. In: *Journal of Cereal Science* 46 (2007), Nr. 1, S. 75 – 81
12. BAO, J.; SHEN, Y. & JIN, L.: Determination of thermal and retrogradation properties of rice starch using near-infrared spectroscopy. In: *Journal of Cereal Science* 46 (2007), Nr. 1, S. 75 – 81
13. BEER, T. D.; BODSON, C.; DEJAEGHER, B.; WALCZAK, B.; VERCRUYSSE, P.; BURGGRAEVE, A.; LEMOS, A.; DELATTRE, L.; HEYDEN, Y. V.; REMON, J.; VERVAET, C. & BAEYENS, W.: Raman spectroscopy as a process analytical technology (PAT) tool for the in-line monitoring and understanding of a powder blending process. In: *Journal of Pharmaceutical and Biomedical Analysis* 48 (2008), Nr. 3, S. 772 – 779
14. BELLON, V.; VIGNEAU, J. L. & SÃ©VILA, F.: Infrared and near-infrared technology for the food industry and agricultural uses: on-line applications. In: *Food Control* 5 (1994), Nr. 1, S. 21 – 27
15. BLANCO, M. & VILLARROYA, I.: NIR spectroscopy: a rapid-response analytical tool. In: *TrAC Trends in Analytical Chemistry* 21 (2002), Nr. 4, S. 240 – 250
16. BURATTI, S.; BALLABIO, D.; GIOVANELLI, G.; DOMINGUEZ, C. Z.; MOLES, A.; BENEDETTI, S. & SINELLI, N.: Monitoring of alcoholic fermentation using near infrared and mid infrared spectroscopies combined with electronic nose and electronic tongue. In: *Analytica Chimica Acta* 697 (2011), Nr. 1â€“2, S. 67 – 74
17. CAI, J.; CHEN, Q.; WAN, X. & ZHAO, J.: Determination of total volatile basic nitrogen (TVB-N) content and Warnerâ€“Bratzler shear force (WBSF) in pork using Fourier transform near infrared (FT-NIR) spectroscopy. In: *Food Chemistry* 126 (2011), Nr. 3, S. 1354 – 1360
18. CEN, H. & HE, Y.: Theory and application of near infrared reflectance spectroscopy in determination of food quality. In: *Trends in Food Science & Technology* 18 (2007), Nr. 2, S. 72 – 83
19. CONSONNI, R. & CAGLIANI, L.: Chapter 4 - Nuclear Magnetic Resonance and Chemometrics to Assess Geographical Origin and Quality of Traditional Food Products. In: TAYLOR, S. L. (Hrsg.): *Academic Press*. 59, 2010, S. 87 – 165
20. CORREDOR, C. C.; BU, D. & BOTH, D.: Comparison of near infrared and microwave resonance sensors for at-line moisture determination in powders and tablets. In: *Analytica Chimica Acta* 696 (2011), Nr. 1â€“2, S. 84 – 93
21. CZARNECKI, M.; CZARNECKA, M.; OZAKI, Y. & IWAHASHI, M.: Are the integrated absorption coefficients temperature dependent? FT-NIR study of the first overtone of the OH stretching mode of octanoic acid. In: *Spectrochimica Acta Part A: Molecular Spectroscopy* 50 (1994), Nr. 8-9, S. 1521 – 1528
22. DOYLE, C. A.; VICKERS, T. J.; MANN, C. K. & DORSEY, J. G.: Characterization of C18-bonded liquid chromatographic stationary phases by Raman spectroscopy:: the effect of temperature. In: *Journal of Chromatography A* 877 (2000), Nr. 1â€“2, S. 41 – 59
23. EBERL, R. & WILKE, J.: NIR spectroscopic application of a refractometric sensor. In: *Sensors and Actuators B: Chemical* 32 (1996), Nr. 3, S. 203 – 208
24. FAGAN, C.; O'DONNELL, C.; RUDZIK, L. & WÃ¼ST, E.: Chapter 10 - Milk and Dairy Products, San Diego: *Academic Press*. : *Infrared Spectroscopy for Food Quality Analysis and Control*., 2009, S. 241 – 273
25. GABRIELE & REICH: Near-infrared spectroscopy and imaging: Basic principles and pharmaceutical applications. In: *Advanced Drug Delivery Reviews* 57 (2005), Nr. 8, S. 1109 – 1143
26. GABRIELE & REICH: Near-infrared spectroscopy and imaging: Basic principles and pharmaceutical applications. In: *Advanced Drug Delivery Reviews* 57 (2005), Nr. 8, S. 1109 – 1143
27. GÃ³MEZ, A. H.; HE, Y. & PEREIRA, A. G.: Non-destructive measurement of acidity, soluble solids and firmness of Satsuma mandarin using Vis/NIR-spectroscopy techniques. In: *Journal of Food Engineering* 77 (2006), Nr. 2, S. 313 – 319
28. GOESAERT, H.; BRIJS, K.; VERAVERBEKE, W.; COURTIN, C.; GEBRUERS, K. & DELCOUR, J.: Wheat flour constituents: how they impact bread quality, and how to impact their functionality. In: *Trends in Food Science & Technology* 16 (2005), Nr. 1â€“3, S. 12 – 30
29. HANS & BÃ¼NING-PFAUE: Analysis of water in food by near infrared spectroscopy. In: *Food Chemistry* 82 (2003), Nr. 1, S. 107 – 115
30. HARBECK, C.; FAURIE, R. & SCHEPER, T.: Application of near-infrared spectroscopy in the sugar industry for the detection of betaine. In: *Analytica Chimica Acta* 501 (2004), Nr. 2, S. 249 – 253
31. HEINZ-DIETER & ISENGARD: Water content, one of the most important properties of food. In: *Food Control* 12 (2001), Nr. 7, S. 395 – 400
32. HUANG, H.; YU, H.; XU, H. & YING, Y.: Near infrared spectroscopy for on/in-line monitoring of quality in foods and beverages: A review. In: *Journal of Food Engineering* 87 (2008), Nr. 3, S. 303 – 313
33. HUANG, L.; WU, D.; JIN, H.; ZHANG, J.; HE, Y. & LOU, C.: Internal quality determination of fruit with bumpy surface using visible and near infrared spectroscopy and chemometrics: A case study with mulberry fruit. In: *Biosystems Engineering* 109 (2011), Nr. 4, S. 377 – 384
34. ISAO & NODA: Two-dimensional correlation spectroscopy â€” Biannual survey 2007â€“2009. In: *Journal of Molecular Structure* 974 (2010), Nr. 1â€“3, S. 3 – 24
35. JAILLAIS, B.; PINTO, R.; BARROS, A. & RUTLEDGE, D.: Outer-product analysis (OPA) using PCA to study the influence of temperature on NIR spectra of water. In: *Vibrational Spectroscopy* 39 (2005), Nr. 1, S. 50 – 58
36. JERRY & JR., W.: 12 - Review of Near-Infrared and Infrared Spectroscopy, Burlington: *Academic Press*. : *The Handbook of Organic Compounds*., 2001, S. 79 – 129
37. KAJIYA, J. T. & HERZEN, B. P. V.: Ray Tracing Volume Densities, 1984
38. KALININ, A.; KRASHENINNIKOV, V. & POTAPOV, A.: Effect of dispersion structure variation on chemometrical calibration of near-infrared spectrometer: Protein fractions in milk and reversed micelles solutions. In: *Chemometrics and Intelligent Laboratory Systems* 97 (2009), Nr. 1, S. 33 – 38
39. KALININ, A.; KRASHENINNIKOV, V. & POTAPOV, A.: Effect of dispersion structure variation on chemometrical calibration of near-infrared spectrometer: Protein fractions in milk and reversed micelles solutions. In: *Chemometrics and Intelligent Laboratory Systems* 97 (2009), Nr. 1, S. 33 – 38
40. KARANDE, A. D.; HENG, P. W. S. & LIEW, C. V.: In-line quantification of micronized drug and excipients in tablets by near infrared (NIR) spectroscopy: Real time monitoring of tabletting process. In: *International Journal of Pharmaceutics* 396 (2010), Nr. 1-2, S. 63 – 74
41. KENNEDY, J. F. & JUMEL, K.: Near infrared spectroscopy in food analysis: By B. G. Osborne and T. Fearn. Longman Scientific & Technical, Harlow. 1987. vii + 200 pp., ISBN 0-582-49489-3. Price: Â£29.95. In: *Carbohydrate Polymers* 7 (1987), Nr. 4, S. 327
42. KOLLER, D.; POSCH, A.; HÃ¶RL, G.; VOURA, C.; RADL, S.; URBANETZ, N.; FRASER, S.; TRITTHART, W.; REITER, F.; SCHLINGMANN, M. & KHINAST, J.: Continuous quantitative monitoring of powder mixing dynamics by near-infrared spectroscopy. In: *Powder Technology* 205 (2011), Nr. 1â€“3, S. 87 – 96
43. L., G. & BOSCO: James L. Waters Symposium 2009 on near-infrared

spectroscopy. In: *TrAC Trends in Analytical Chemistry* 29 (2010), Nr. 3, S. 197 – 208

44. L.B., D. & WETZEL: Analytical near infrared spectroscopy. In: WETZEL, D. L. B. & CHARALAMBOUS, G. (Hrsg.): *Elsevier*. 39 : *Instrumental Methods in Food and Beverage Analysis*., 1998, S. 141 – 194
45. LARRECHI, M. & CALLAO, M.: Strategy for introducing NIR spectroscopy and multivariate calibration techniques in industry. In: *TrAC Trends in Analytical Chemistry* 22 (2003), Nr. 9, S. 634 – 640
46. LARS & NÃ¸RGAARD: Direct standardisation in multi wavelength fluorescence spectroscopy. In: *Chemometrics and Intelligent Laboratory Systems* 29 (1995), Nr. 2, S. 283 – 293
47. LEUNG, T. S.; TACHTSIDIS, I.; VELAYUTHAN, P.; HENTY, J. R.; JONES, H.; SMITH, M.; ELWELL, C. E. & DELPY, D. T.: Investigation of Oxygen saturation derived from cardiac pulsations measured on the adult head using NIR Spectroscopy
48. LIN, H.; ZHAO, J.; SUN, L.; CHEN, Q. & ZHOU, F.: Freshness measurement of eggs using near infrared (NIR) spectroscopy and multivariate data analysis. In: *Innovative Food Science & Emerging Technologies* 12 (2011), Nr. 2, S. 182 – 186
49. LIN, M.; RASCO, B. A.; CAVINATO, A. G. & AL-HOLY, M.: Chapter 6 - Infrared (IR) Spectroscopyâ€"Near-Infrared Spectroscopy and Mid-Infrared Spectroscopy, San Diego: *Academic Press*. : *Infrared Spectroscopy for Food Quality Analysis and Control*., 2009, S. 119 – 143
50. LIU, Y.; SUN, X.; ZHOU, J.; ZHANG, H. & YANG, C.: Linear and nonlinear multivariate regressions for determination sugar content of intact Gannan navel orange by Visâ€"NIR diffuse reflectance spectroscopy. In: *Mathematical and Computer Modelling* 51 (2010), Nr. 11-12, S. 1438 – 1443
51. LUYPAERT, J.; MASSART, D. & HEYDEN, Y. V.: Near-infrared spectroscopy applications in pharmaceutical analysis. In: *Talanta* 72 (2007), Nr. 3, S. 865 – 883
52. MÃ¼LLER, A. & STEINHART, H.: Recent developments in instrumental analysis for food quality. In: *Food Chemistry* 101 (2007), Nr. 3, S. 1136 – 1144
53. MALINEN, J.; KÃ¤NSÃ¤KOSKI, M.; RIKOLA, R. & EDDISON, C. G.: LED-based NIR spectrometer module for hand-held and process analyser applications. In: *Sensors and Actuators B: Chemical* 51 (1998), Nr. 1-3, S. 220 – 226
54. MANTANUS, J.; ZIÃ©MONS, E.; LEBRUN, P.; ROZET, E.; KLINKENBERG, R.; STREEL, B.; EVRARD, B. & HUBERT, P.: Moisture content determination of pharmaceutical pellets by near infrared spectroscopy: Method development and validation. In: *Analytica Chimica Acta* 642 (2009), Nr. 1â€"2, S. 186 – 192
55. MARABI, A.; RAEMY, A.; BAUWENS, I.; BURBIDGE, A.; WALLACH, R. & SAGUY, I.: Effect of fat content on the dissolution enthalpy and kinetics of a model food powder. In: *Journal of Food Engineering* 85 (2008), Nr. 4, S. 518 – 527
56. MAZEROLLES, G.; HANAFI, M.; DUFOUR, E.; BERTRAND, D. & QANNARI, E.: Common components and specific weights analysis: A chemometric method for dealing with complexity of food products. In: *Chemometrics and Intelligent Laboratory Systems* 81 (2006), Nr. 1, S. 41 – 49
57. MCGLONE, V. & KAWANO, S.: Firmness, dry-matter and soluble-solids assessment of postharvest kiwifruit by NIR spectroscopy. In: *Postharvest Biology and Technology* 13 (1998), Nr. 2, S. 131 – 141
58. MCQUEEN, D. H.; WILSON, R.; KINNUNEN, A. & JENSEN, E. P.: Comparison of two infrared spectroscopic methods for cheese analysis. In: *Talanta* 42 (1995), Nr. 12, S. 2007 – 2015
59. MORALES-SILLERO, A.; FERNÃ¡NDEZ-CABANÃ¡S, V.-M.; CASANOVA, L.; JIMÃ©NEZ, M.-R.; SUÃ¡REZ, M.-P. & RALLO, P.: Feasibility of NIR spectroscopy for non-destructive characterization of table olive traits. In: *Journal of Food Engineering* 107 (2011), Nr. 1, S. 99 – 106
60. MORENO, P. R.; ROBERT, M.; LODDER, A. & PURUSHOTHAMAN, P. K. R.: Detection of Lipid Pool, Thin Fibrous Cap, and Inflammatory Cells in Human Aortic Atherosclerotic Plaques by Near-Infrared Spectroscopy,
61. NICOLAÃ¯, B. M.; BEULLENS, K.; BOBELYN, E.; PEIRS, A.; SAEYS, W.; THERON, K. I. & LAMMERTYN, J.: Nondestructive measurement of fruit and vegetable quality by means of NIR spectroscopy: A review. In: *Postharvest Biology and Technology* 46 (2007), Nr. 2, S. 99 – 118
62. NUMATA, Y.; IIDA, Y. & TANAKA, H.: Quantitative analysis of alcoholâ€"water binary solutions using Raman spectroscopy. In: *Journal of Quantitative Spectroscopy and Radiative Transfer* 112 (2011), Nr. 6, S. 1043 – 1049
63. OHYAMA, Y.; ONAKA, T.; MATSUHARA, H.; WADA, T.; KIM, W.; FUJISHIRO, N.; UEMIZU, K.; SAKON, I.; COHEN, M.; ISHIGAKI, M.; ISHIHARA, D.; ITA, Y.; KATAZA, H.; MATSUMOTO, T.; MURAKAMI, H.; OYABU, S.; TANABE, T.; TAKAGI, T.; UENO, M.; USUI, F.; WATARAI, H.; PEARSON, C. P.; TAKEYAMA, N.; YAMAMURO, T. & IKEDA, Y.: Near-infrared and Mid-infrared Spectroscopy with the Infrared Camera (IRC) for AKARI, 2007
64. OTSUKA, M.; MOURI, Y. & MATSUDA, Y.: Chemometric Evaluation of Pharmaceutical Properties of Antipyrine Granules by Near-Infrared Spectroscopy, 2002
65. OTTESTAD, S.; ISAKSSON, T. & WOLD, J. P.: Effect of varying optical properties on the modeling of astaxanthin concentration in salmon by visible spectroscopy. In: *Aquaculture* (2011), Nr. 0, S.
66. PAREYT, B. & DELCOUR, J. A.: The Role of Wheat Flour Constituents, Sugar, and Fat in Low Moisture Cereal Based Products: A Review on Sugar-Snap Cookies. In: *Critical Reviews in Food Science and Nutrition* 48 (2008), Nr. 9, S. 824-839
67. PEDRESCHI, F.; SEGTNAN, V. & KNUTSEN, S.: On-line monitoring of fat, dry matter and acrylamide contents in potato chips using near infrared interactance and visual reflectance imaging. In: *Food Chemistry* 121 (2010), Nr. 2, S. 616 – 620
68. PEINADO, A.; VAN DEN BERG, F.; BLANCO, M. & BRO, R.: Temperature-induced variation for NIR tensor-based calibration. In: *Chemometrics and Intelligent Laboratory Systems* 83 (2006), Nr. 1, S. 75 – 82
69. PURNOMOADI, A.; BATAJOO, K. K.; UEDA, K. & TERADA, F.: Influence of feed source on determination of fat and protein in milk by near-infrared spectroscopy. In: *International Dairy Journal* 9 (1999), Nr. 7, S. 447 – 452
70. R.K. & SCOPES: Measurement of protein by spectrophotometry at 205 nm. In: *Analytical Biochemistry* 59 (1974), Nr. 1, S. 277 – 282
71. R.L. & WEHLING: SPECTROSCOPY | Near-infrared. In: IN CHIEF:Â Â BENJAMIN CABALLERO, E. (Hrsg.), Oxford: *Academic Press*. : *Encyclopedia of Food Sciences and Nutrition (Second Edition)*., 2003, S. 5426 – 5431
72. RANTANEN, J.; RÃ¤SÃ¤NEN, E.; TENHUNEN, J.; KÃ¤NSÃ¤KOSKI, M.; MANNERMAA, J.-P. & YLIRUUSI, J.: In-line moisture measurement during granulation with a four-wavelength near infrared sensor: an evaluation of particle size and binder effects. In: *European Journal of Pharmaceutics and Biopharmaceutics* 50 (2000), Nr. 2, S. 271 – 276
73. REID, L. M.; O'DONNELL, C. P. & DOWNEY, G.: Recent technological advances for the determination of food authenticity. In: *Trends in Food Science & Technology* 17 (2006), Nr. 7, S. 344 – 353
74. REN, G. & CHEN, F.: Determination of moisture content of ginseng by near infra-red reflectance spectroscopy. In: *Food Chemistry* 60 (1997), Nr. 3, S. 433 – 436
75. RILEY, M. R. & CRIDER, H. M.: The effect of analyte concentration range on measurement errors obtained by NIR spectroscopy. In: *Talanta* 52 (2000), Nr. 3, S. 473 – 484
76. RODRIGUEZ-SAONA, L. E.; FRY, F. S.; MCLAUGHLIN, M. A. & CALVEY, E. M.: Rapid analysis of sugars in fruit juices by FT-NIR spectroscopy. In: *Carbohydrate Research* 336 (2001), Nr. 1, S. 63 – 74
77. ROGGO, Y.; CHALUS, P.; MAURER, L.; LEMA-MARTINEZ, C.;

EDMOND, A. & JENT, N.: A review of near infrared spectroscopy and chemometrics in pharmaceutical technologies. In: *Journal of Pharmaceutical and Biomedical Analysis* 44 (2007), Nr. 3, S. 683 – 700

78. ROSENVOLD, K.; MICKLANDER, E.; HANSEN, P. W.; BURLING-CLARIDGE, R.; CHALLIES, M.; DEVINE, C. & NORTH, M.: Temporal, biochemical and structural factors that influence beef quality measurement using near infrared spectroscopy. In: *Meat Science* 82 (2009), Nr. 3, S. 379 – 388
79. RUIZ-ALTISENT, M.; RUIZ-GARCIA, L.; MOREDA, G.; LU, R.; HERNANDEZ-SANCHEZ, N.; CORREA, E.; DIEZMA, B.; NICOLAÃ¯, B. & GARCÃ-A-RAMOS, J.: Sensors for product characterization and quality of specialty cropsâ€"A review. In: *Computers and Electronics in Agriculture* 74 (2010), Nr. 2, S. 176 – 194
80. SALAMATI, N.; FREDEMBACH, C. & SÜSSTRUNK, S.: Material Classification Using Color and NIR Images,
81. SCHAARE, P. & FRASER, D.: Comparison of reflectance, interactance and transmission modes of visible-near infrared spectroscopy for measuring internal properties of kiwifruit (Actinidia chinensis). In: *Postharvest Biology and Technology* 20 (2000), Nr. 2, S. 175 – 184
82. SCHERZER, T. & DECKER, U.: The effect of temperature on the kinetics of diacrylate photopolymerizations studied by Real-time FTIR spectroscopy. In: *Polymer* 41 (2000), Nr. 21, S. 7681 – 7690
83. SCHNEIDER, W.-D. & BERNDT, R.: Low-temperature scanning tunneling spectroscopy:: Kondo effect and surface state lifetimes. In: *Journal of Electron Spectroscopy and Related Phenomena* 109 (2000), Nr. 1â€"2, S. 19 – 31
84. SCHRADER, B.; DIPPEL, B.; ERB, I.; KELLER, S.; LÃ¶CHTE, T.; SCHULZ, H.; TATSCH, E. & WESSEL, S.: NIR Raman spectroscopy in medicine and biology: results and aspects. In: *Journal of Molecular Structure* 480-481 (1999), Nr. 0, S. 21 – 32
85. SCHRADER, B. & KELLER, S.: SPECTROSCOPY | Infrared and Raman. In: IN CHIEF:Â Â BENJAMIN CABALLERO, E. (Hrsg.), Oxford: *Academic Press*. : *Encyclopedia of Food Sciences and Nutrition (Second Edition)*., 2003, S. 5410 – 5426
86. SEGTNAN, V. H. & ISAKSSON, T.: Temperature, sample and time dependent structural characteristics of gelatine gels studied by near infrared spectroscopy. In: *Food Hydrocolloids* 18 (2004), Nr. 1, S. 1 – 11
87. SHAPIRO, Y. E.: SPECTROSCOPY,
88. SHAW, R. A. & MANTSCH, H. H.: Near-IR Spectrometers. In: IN CHIEF:Â Â JOHN C. LINDON, E. (Hrsg.), Oxford: *Elsevier*. : *Encyclopedia of Spectroscopy and Spectrometry*., 1999, S. 1451 – 1461
89. SHAW, R. A. & MANTSCH, H. H.: Near-IR Spectrometers. In: IN CHIEF:Â Â JOHN LINDON, E. (Hrsg.), Oxford: *Academic Press*. : *Encyclopedia of Spectroscopy and Spectrometry (Second Edition)*., 1999, S. 1738 – 1747
90. SHIROMA, C. & RODRIGUEZ-SAONA, L.: Application of NIR and MIR spectroscopy in quality control of potato chips. In: *Journal of Food Composition and Analysis* 22 (2009), Nr. 6, S. 596 – 605
91. SINGH, P.; BHAMIDIPATI, S.; SINGH, R.; SMITH, R. & NELSON, P.: Evaluation of in-line sensors for prediction of soluble and total solids/moisture in continuous processing of fruit juices. In: *Food Control* 7 (1996), Nr. 3, S. 141 – 148
92. SMITH-MORITZ, A. M.; CHERN, M.; LAO, J.; SZE-TO, W.; HEAZLEWOOD, J. L.; RONALD, P. C. & VEGA-SANCHEZ, M. E.: Combining multivariate analysis and monosaccharide composition modeling to identify plant cell wall variations by Fourier Transform Near Infrared spectroscopy, 2011
93. STEFANO & ZARDETTO: Potential applications of near infrared spectroscopy for evaluating thermal treatments of fresh egg pasta. In: *Food Control* 16 (2005), Nr. 3, S. 249 – 256
94. SUBRAMANIAN, A.; PRABHAKAR, V. & RODRIGUEZ-SAONA, L.: Analytical Methods | Infrared Spectroscopy in Dairy Analysis. In: IN CHIEF:Â Â JOHN W. FUQUAY, E. (Hrsg.), San Diego: *Academic Press*. : *Encyclopedia of Dairy Sciences (Second Edition)*., 2011, S. 115 – 124
95. T. & FROST: Quantitative Analysis. In: IN CHIEF:Â Â JOHN C. LINDON, E. (Hrsg.), Oxford: *Elsevier*. : *Encyclopedia of Spectroscopy and Spectrometry*., 1999, S. 1931 – 1936
96. T.N. & MCCAIG: Extending the use of visible/near-infrared reflectance spectrophotometers to measure colour of food and agricultural products. In: *Food Research International* 35 (2002), Nr. 8, S. 731 – 736
97. THYHOLT, K.; ENERSEN, G. & ISAKSSON, T.: Determination of endpoint temperatures in previously heat treated beef using reflectance spectroscopy. In: *Meat Science* 48 (1998), Nr. 1â€"2, S. 49 – 63
98. TIAN, Q.; TONG, Q.; PU, R.; GUO, X. & ZHAO, C.: Spectroscopic determination of wheat water status using 1650-1850 nm spectral absorption features. In: *International Journal of Remote Sensing* 22 (2001), Nr. 12, S. 2329-2338
99. VÃ¡LYI-NAGY, I.; KAFFKA, K. J.; JÃ¡KÃ³, J. M.; Ã‰VA GÃ¶NCZÃ¶L & DOMJÃ¡N, G.: Application of near infrared spectroscopy to the determination of haemoglobin. In: *Clinica Chimica Acta* 264 (1997), Nr. 1, S. 117 – 125
100. VALENTE, M.; LEARDI, R.; SELF, G.; LUCIANO, G. & PAIN, J. P.: Multivariate calibration of mango firmness using vis/NIR spectroscopy and acoustic impulse method. In: *Journal of Food Engineering* 94 (2009), Nr. 1, S. 7 – 13
101. VALOUS, N. A.; MENDOZA, F. & SUN, D.-W.: Emerging non-contact imaging, spectroscopic and colorimetric technologies for quality evaluation and control of hams: a review. In: *Trends in Food Science & Technology* 21 (2010), Nr. 1, S. 26 – 43
102. VANARASE, A. U.; ALCALÃ , M.; ROZO, J. I. J.; MUZZIO, F. J. & ROMAÃ±ACH, R. J.: Real-time monitoring of drug concentration in a continuous powder mixing process using NIR spectroscopy. In: *Chemical Engineering Science* 65 (2010), Nr. 21, S. 5728 – 5733
103. VICKERY, H. B.: The Constituents of Wheat and Wheat Products (Bailey, C. H.). In: *Journal of Chemical Education* 22 (1945), Nr. 1, S. 51
104. W., G. & SMALL: Chemometrics and near-infrared spectroscopy: Avoiding the pitfalls. In: *TrAC Trends in Analytical Chemistry* 25 (2006), Nr. 11, S. 1057 – 1066
105. WILLIAMS, P. C. & STEVENSEN, S. G.: Near-infrared reflectance analysis: food industry applications. In: *Trends in Food Science & Technology* 1 (1990), Nr. 0, S. 44 – 48
106. WU, D.; FENG, S. & HE, Y.: Infrared Spectroscopy Technique for the Nondestructive Measurement of Fat Content in Milk Powder. In: *Journal of Dairy Science* 90 (2007), Nr. 8, S. 3613 – 3619
107. WU, J. & SHI, C.: Calibration model optimization for rice cooking characteristics by near infrared reflectance spectroscopy (NIRS). In: *Food Chemistry* 103 (2007), Nr. 3, S. 1054 – 1061
108. WU, J. & SHI, C.: Calibration model optimization for rice cooking characteristics by near infrared reflectance spectroscopy (NIRS). In: *Food Chemistry* 103 (2007), Nr. 3, S. 1054 – 1061
109. XIAOBO, Z.; JIEWEN, Z.; POVEY, M. J.; HOLMES, M. & HANPIN, M.: Variables selection methods in near-infrared spectroscopy. In: *Analytica Chimica Acta* 667 (2010), Nr. 1â€"2, S. 14 – 32
110. XIE, S.; XIANG, B.; YU, L. & DENG, H.: Tailoring noise frequency spectrum to improve NIR determinations. In: *Talanta* 80 (2009), Nr. 2, S. 895 – 902
111. YU, H.; NIU, X.; LIN, H.; YING, Y.; LI, B. & PAN, X.: A feasibility study on on-line determination of rice wine composition by Visâ€"NIR spectroscopy and least-squares support vector machines. In: *Food Chemistry* 113 (2009), Nr. 1, S. 291 – 296
112. ZHANG, X. & WYETH, P.: Moisture sorption as a potential condition marker for historic silks: noninvasive determination by near-infrared spectroscopy 61, 2007, S. 2
113. Second european symposium on near infrared (NIR) spectroscopy: Aspects of industrial use. In: *Chemometrics and Intelligent*

Laboratory Systems 18 (1993), Nr. 2, S. 230 - 231

