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近红外光谱技术在茶叶中的研究进展

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摘要 传统的茶叶品质感官审评方法和湿化学检测方法具有结果评价主观性强、测定费时、费力等局限性,而近红外光谱技术作为一种新型的分析技术手段,具有快速、无损、结果客观等优势,在茶行业上得到应用。本文在概述近红外光谱技术原理基础上,主要综述了近红外光谱技术在茶鲜叶品质分析、成分检测、茶叶等级识别、茶种类鉴别、茶地理溯源和茶叶深加工产品分析等方面的应用进展,分析了近红外光谱技术在应用过程中存在的问题,并针对性地提出了应对策略,以期为近红外光谱技术在茶行业的广泛应用提供参考。

关键词 近红外光谱;茶叶;品质分析;等级评价;种类鉴别;茶地理溯源;茶深加工产品分析

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我国是茶的故乡,发现和利用茶已有4 000 a历史,是全球最大的茶叶种植和生产大国,2020年茶园种植面积和茶产量分别为316.5万 hm^2 和297万t,较2019年分别增长了3.3%和6.9%[1]。随着人们逐渐重视健康与保健,保健茶备受人们的青睐,对茶品质如何进行快速准确地评判和有效控制是当前茶产业发展面临的主要问题之一。

传统的茶品质评价方法主要有感官审评法和湿化学检测法[2]。感官审评法是由训练有素的专家利用自身视觉、嗅觉、味觉等分别对茶的外形、汤色、香气、滋味和叶底进行评价打分,计算茶品质总分。尽管该方法较为经典,但结果易受审评员自身感觉器官等因素影响,主观性较强[3]。湿化学检测法通常需要借助多种检测仪器(如高效液相色谱仪(HPLC)[4]、气相色谱仪(GC)[5]、高效液相色谱质谱联用仪(HPLC-MS)[6]和气相色谱质谱联用仪(GC-MS)[7]),精准测定茶叶中内含成分含量来评价茶品质高低。虽然该方法测定结果准确、客观,但测定前样品需进行复杂的预处理,测定时需使用大量有毒化学试剂,且操作繁琐、耗时费力、检测成本高,还无法实时检测茶品质。因此,如何科学、有效、客观地评价茶品质是一个亟待解决的难题。

近年来,研究者已应用多种检测技术快速评价茶品质,如近红外光谱技术[8]、高光谱成像技术、电子鼻和电子舌技术等[9]。其中,近红外光谱技术是一种新兴技术,通过扫描获得茶内含物的全部光谱信息,借助化学计量学方法提取与茶品质密切相关的光谱波段或数据点信息,建立专有预测模型,实现茶品质的快速、实时监测。此外,近红外光谱技术还具有独特的优势,能准确判别茶种类和茶产地溯源等,能够满足生产上实时检测的需求[10]。本文重点介绍了近红外光谱技术在茶叶上的应用现状,以期加快近红外光谱技术在茶行业的普及和应用。

1 近红外光谱技术介绍

近红外光谱(near infrared spectroscopy,NIRS)是一种电磁波(波长780～2 526 nm),主要反映的是样品内部含氢基团(如—OH、—CH、—NH和—PH)化学键伸缩振动倍频与合频吸收信息[11]。近红外光谱被样品分子吸收并引起振动,从

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基态跃迁到激发态，通过分析这些光谱用于预测物质的含量和结构[12-13]。NIRS 分析速度快、检测准确度高，不破坏样品，不污染环境，结合多种化学计量学方法和计算机技术，用于定性分析和定量研究[14-16]。

早在 20 世纪 40 年代，近红外光谱技术就被应用于对木材开展相关研究[17]，但由于实验条件有限，未能取得较大成果；随着光谱技术不断进步，人们尝试应用 NIRS 检测谷物水分和蛋白质含量[18]，紧接着出现了采用积分球测量技术提高信号强度的近红外光谱分析仪，增加了防尘和控制仪器内部温度的设备。随着编程语言的发展和分析技术手段的提高，近红外光谱技术不断得到深入发展，分析稳定性逐步提升，已被广泛应用于农副产品[19-20]和石油化工[21-23]等领域。

2　近红外光谱技术在茶叶上的应用

2.1　茶鲜叶

近红外光谱技术在茶鲜叶上的应用取得了一些新进展。王胜鹏等[24]采用偏最小二乘（PLS）法分别建立了茶鲜叶水分、粗纤维和全氮含量的快速预测模型，首次得出了鲜叶原料品质系数计算方法（quality index，QI），QI 越大，鲜叶品质越好。为提高预测模型精度，王胜鹏等[25]建立了 QI 人工神经网络模型（$R^2_{pre}=0.922\ 3$），开展了恩施玉露茶鲜叶产地[26]和价格 NIRS 无损预测[27]，基于 S/B 模型传递算法[28]解决了多品种茶鲜叶品质 NIRS 模型适用性难题[29]。此外，王胜鹏等[30-31]还在不同土壤类型茶鲜叶和不同栽培环境茶鲜叶品种判别等方面做了大量研究，实现了快速准确鉴别。

2.2　茶叶成分检测

近红外光谱技术在茶叶成分无损检测上的应用主要包括对茶多酚[32]、氨基酸[33]、咖啡碱[34]、水浸出物[35]和儿茶素组分[36]等的分析。Schulz 等[37]利用近红外光谱技术结合 PLS 建立了茶多酚和咖啡碱的预测模型，预测决定系数大于 0.85；Luypaert 等[38]建立了茶叶总抗氧化能力的 NIRS-PLS 定量分析模型，拓展了 NIRS 的应用范围；徐立恒等[39]应用 NIRS 分别结合二阶导数和 PLS 法建立了茶多酚、氨基酸及咖啡碱三类化合物的预测模型，相关系数均大于 0.98，且没有出现过拟合现象。为提高预测模型精度，王毅等[40]先应用小波去噪方法剔除大量噪声信息，再结合特征光谱区间筛选方法建立茶多酚 iPLS-GA 预测模型；赵杰文等[41]尝试应用正交信号校正法去掉部分噪声信息后建立了 EGCG 近红外光谱预测模型；陈全胜等[42]采用净分析物预处理法提取出待测组分的净分析物信号，应用 PLS 法建立了 EGCG、ECG 和 EGC 这 3 种茶多酚含量的预测模型；耿响等[43]采用小波分析-移动窗口偏最小二乘法，建立了咖啡碱含量预测模型，预测相关系数提高到了 0.962 5。

2.3　茶叶等级评价

Hall 等[44]通过对 134 个不同地区、不同品质的红茶茶样与近红外光谱进行关联分析，证实了 NIRS 可以用于茶叶等级评价。阎守和等[45-46]进一步探索了近红外法直接用于评价茶叶品质的可行性研究。以 96 个国家级标准红茶、绿茶茶样为研究对象，应用多元线性回归方法建立茶叶等级与审评结果间的相关分析，相关系数达到 0.836；为进一步提升茶等级评价的效果，其应用 PLS 方法建立预测模型，只有 2 个茶样被错判；利用上述近红外光谱回归方程，对布隆迪茶厂不同等级的红碎茶茶样进行测定，试验结果与已有研究结论相符。周小芬等[47]分别建立了大佛龙井的干茶色泽、汤色、香气、滋味和叶底得分及总品质分数的 NIRS 定量分析模型，均达到较高的预测精度，且五因子总分模型预测效果最佳。

2.4　茶叶种类判别

Chen 等[48]建立了乌龙茶、红茶和绿茶近红外光谱模型，建模集和预测集判别率均大于 90%，并在 6 500～5 300 cm^{-1} 内进行 SNV 预处理，建立龙井、碧螺春、祁红和铁观音 4 种茶 NIRS 识别模型[49]，判别准确率分别为 90%、80%、100% 和 100%；赵杰文等[50]应用 PCA-MD 法建立了 4 种名优茶（铁观音茶、碧螺春、龙井和毛峰）的判别模型，建模集和验证集模型判别正确率分别达到98.75% 和 95%；Wang 等[51]利用 PCA 方法提取光谱信息，再应用随机森林方法建立 5 种不同多酚含量的绿茶 NIRS 预测模型，准确率达到 96%；牛智友等[52]应用 PCA 结合多种聚类分析法建立的 4 种不同类型茶的定性判别模型，准确率达到 100%；李晓丽等[53]以前 6 个主成分作为输入变量，建立西湖龙井等 5 种绿茶的 3 层 BP-ANN 预测模型，模型对验证集样本的品种判别准确率达到 100%。

2.5 茶叶地理溯源

由于茶叶产地的环境、日照强度、时间和土壤理化性质等方面存在差异，加工出的茶叶品质也不同，很难用眼睛判别茶叶产地，因此借助近红外光谱技术开展茶叶产地溯源研究，有利于茶品质的控制。

Ren 等[54]扫描了中国、印度、肯尼亚、斯里兰卡和缅甸的 140 个红茶样品，建立了咖啡碱等 4 种内含成分的 NIRS-PLS 模型，再应用因子法成功实现了建模红茶样品的产地判别；Diniz 等[55]应用独立软模式等 3 种定性方法对不同国家的绿茶产地进行判别，最佳模型为连续投影算法-线性判别模型。陈全胜等[56]对 6 500～5 500 cm^{-1} 进行 SNV 预处理后进行主成分分析，建立了碧螺春茶判别模型，校正集样品的判别准确率为 93.5%；Yan 等[57]利用 NIRS-PLS 分析法建立了安溪铁观音和与仿冒铁观音茶的判别模型，实现了真假铁观音的快速判别；Xu 等[58]研究实现了真伪安吉白茶的快速判别。

2.6 茶叶深加工

茶叶深加工是延长茶产业链、增加茶产品附加值的一个重要措施。Li 等[59]将近红外光谱技术应用于茶饮料可溶性固体含量的快速无损检测，建立了标的物 PLS 和多元线性回归模型，真值与预测值间具有较高的线性相关性；Liu 等[60]对速溶奶茶进行了 NIRS 分类识别，取得了较好的效果。由此可见，NIRS 技术在茶叶深加工领域有着广泛的应用前景。

2.7 国产近红外光谱仪器的研制

安徽农业大学张正竹教授研究团队采用光栅型分光方式，在国内率先研制了茶鲜叶品质分析仪（sNIR-2201 茶叶品质分级仪）[24]，该仪器能够准确地预测鲜叶的品质系数。此后，该团队又研制出了便携式茶叶质量快速检测装备以及耦合型智能手机茶叶质量快速检测分析仪[61-62]，实现了茶叶质量在线便捷检测。Wang 等[63]应用智能手机控制微型近红外光谱仪，实现了儿茶素、咖啡碱和营养成分含量的快速检测。Huang 等[61]和 Wang 等[64]分别利用手持 NIRS 光谱仪实现了滇红茶等级和抹茶产品质量的快速预测与评价。

3 存在的问题与对策

与传统方法相比，近红外光谱技术具有预测结果准确、客观，样品无需预处理等优势，在茶叶上有着广阔的应用前景。但目前尚存在一些制约因素，影响了近红外光谱技术在茶行业的大规模应用，主要问题如下：

1）建立的某一指标的近红外光谱预测模型均有一定的适用范围，当预测某未知样品指标时，必须先将未知样品与建模样品进行相同的预处理才行，否则模型预测误差较大。在近红外光谱模型建立过程中需要采集大量的代表性建模样本，取样难度大，样品收集困难较多，需付出大量的人力、物力和财力成本。模型建好后，还需要常态化模型维护，为使模型不断适应新的样品背景信息，需要向模型中添加新的建模样品。因此，在应用近红外光谱技术时，要着重解决模型的适用性难题。

2）近红外光谱技术作为二次分析技术，检测的灵敏度不如湿化学检测法。近红外光谱模型更适用于常量分析，不适合于痕量分析。目前在茶叶检测项目中，农残的检出限要求很低，因此，现有的近红外光谱技术还不能大规模取代已成熟的湿化学检测方法。

3）目前已有的近红外光谱仪价格较为昂贵，且高端的仪器大部分均为进口，短时间内国内尚不具备成熟的零部件配套体系，采购成本高，较难为茶叶企业接受。国内生产的近红外光谱仪虽然在价格上优势明显，但在仪器精度和稳定性方面尚存在一定差距，因此，市场推广难度较大。

因此，在今后尚需从以下几个方面加大近红外光谱技术研发力度：

1）为不断增强近红外光谱模型的适用性，降低建模成本，应加大模型转移算法方面的研究工作，使模型在复杂的背景下也具有较好的预测精度和准确性。

2）在检测方法上，统一样品前处理、操作规程的标准体系建设，统一行业内部检测条件，建立稳健的近红外光谱模型，并逐渐扩大近红外光谱技术的应用范围。

3）加大国内近红外光谱仪器的研发力度，提高仪器的精度和稳定性，加大市场推广，降低近红外光谱仪器价格，鼓励国内从事近红外光谱技术研究的单位和科研人员优先采购和使用国产近红外光谱仪，并有针对性地提出仪器的改进建议，以提高国产近红外光谱分析仪的市场竞争力。

参考文献 References

[1] REN G X, FAN Q Y, HE X J, et al. Applicability of multifunctional preprocessing device for simultaneous estimation of spreading of green tea, withering of black tea and shaking of oolong tea[J]. Journal of the science of food and agriculture, 2020, 100(2): 560-569.

[2] REN G X, WANG S P, NING J M, et al. Quantitative analysis and geographical traceability of black tea using Fourier transform near-infrared spectroscopy (FT-NIRS)[J]. Food research international, 2013, 53(2): 822-826.

[3] ZAREEF M, CHEN Q S, OUYANG Q, et al. Prediction of amino acids, caffeine, theaflavins and water extract in black tea using FT-NIR spectroscopy coupled chemometrics algorithms [J]. Analytical methods, 2018, 10(25): 3023-3031.

[4] GUO Z M, BARIMAH A O, SHUJAT A, et al. Simultaneous quantification of active constituents and antioxidant capability of green tea using NIR spectroscopy coupled with swarm intelligence algorithm[J/OL]. LWT-food science and technology, 2020, 129: 109510[2021-05-01]. https://doi.org/10.1016/j.lwt.2020.109510.

[5] FANG S M, NING J M, HUANG W J, et al. Identification of geographical origin of Keemun black tea based on its volatile composition coupled with multivariate statistical analyses[J]. Journal of the science of food and agriculture, 2019, 99(9): 4344-4352.

[6] XU S S, WANG J J, WEI Y M, et al. Metabolomics based on UHPLC-orbitrap-MS and global natural product social molecular networking reveals effects of time scale and environment of storage on the metabolites and taste quality of raw Pu-erh tea [J]. Journal of agricultural and food chemistry, 2019, 67(43): 12084-12093.

[7] XU J Y, WANG M, ZHAO J P, et al. Yellow tea (*Camellia sinensis* L.), a promising Chinese tea: processing, chemical constituents and health benefits[J]. Food research international, 2018, 107: 567-577.

[8] 王胜鹏，郑鹏程，龚自明，等. 青砖茶茶汤滋味品质的近红外快速无损评价[J]. 华中农业大学学报，2020，39(3)：113-119.
WANG S P, ZHENG P C, GONG Z M, et al. Rapid evaluation of taste quality for Qingzhuan tea soup based on near infrared spectroscopy[J]. Journal of Huazhong Agricultrural University, 2020, 39(3): 113-119(in Chinese with English abstract).

[9] REN G X, NING J M, ZHANG Z Z. Intelligent assessment of tea quality employing visible-near infrared spectra combined with a hybrid variable selection strategy[J/OL]. Microchemical journal, 2020, 157: 105085[2021-05-01]. https://doi.org/10.1016/j.microc.2020.105085.

[10] JIANG H, WANG W, MEI C L, et al. Rapid diagnosis of normal and abnormal conditions in solid-state fermentation of bioethanol using Fourier transform near-infrared spectroscopy[J]. Energy & fuels, 2017, 31(11): 12959-12964.

[11] JIANG H, XU W D, CHEN Q S. Determination of tea polyphenols in green tea by homemade color sensitive sensor combined with multivariate analysis[J/OL]. Food chemistry, 2020, 319: 126584[2021-05-01]. https://doi.org/10.1016/j.foodchem.2020.126584.

[12] TIKAPUNYA T, HENRY R J, SMYTH H. Evaluating the sensory properties of unpolished Australian wild rice[J]. Food research international, 2018, 103: 406-414.

[13] KORTESNIEMI M, ROSENVALD S, LAAKSONEN O, et al. Sensory and chemical profiles of Finnish honeys of different botanical origins and consumer preferences[J]. Food chemistry, 2018, 246: 351-359.

[14] ESCRIBANO S, BIASI W V, LERUD R, et al. Non-destructive prediction of soluble solids and dry matter content using NIR spectroscopy and its relationship with sensory quality in sweet cherries[J]. Postharvest biology and technology, 2017, 128: 112-120.

[15] BALAGE J M, DA LUZ E SILVA S, GOMIDE C A, et al. Predicting pork quality using Vis/NIR spectroscopy[J]. Meat science, 2015, 108: 37-43.

[16] OUYANG Q, CHEN Q S, ZHAO J W. Intelligent sensing sensory quality of Chinese rice wine using near infrared spectroscopy and nonlinear tools[J]. Spectrochimica acta part A: molecular and biomolecular spectroscopy, 2016, 154: 42-46.

[17] KNIEST C. Characteristic of urea resined wood paticles by NIR spectroscopy[J]. European journal of wood and wood products, 1943, 6(1): 73-78.

[18] NORRIS K H, BARNES R F, MOORE J E, et al. Predicting forage quality by infrared replectance spectroscopy[J]. Journal of animal science, 1976, 43(4): 889-897.

[19] WU D, HE Y, FENG S J, et al. Study on infrared spectroscopy technique for fast measurement of protein content in milk powder based on LS-SVM[J]. Journal of food engineering, 2008, 84(1): 124-131.

[20] COZZOLINO D, MURRAY I. Identification of animal meat muscles by visible and near infrared reflectance spectroscopy [J]. LWT-food science and technology, 2004, 37(4): 447-452.

[21] DE PAULA PEDROZA R H, NICÁCIO J T N, DOS SANTOS B S, et al. Determining the kinematic viscosity of lubricant oils for gear motors by using the near infrared spectroscopy (NIRS) and the wavelength selection[J]. Analytical letters, 2013, 46(7): 1145-1154.

[22] HUANG X H, EL-SAYED I H, QIAN W, et al. Cancer cell imaging and photothermal therapy in the near-infrared region by using gold nanorods[J]. Journal of the American chemical society, 2006, 128(6): 2115-2120.

[23] BÜNZLI J C G, PIGUET C. Taking advantage of luminescent lanthanide ions[J]. Chemical society reviews, 2005, 34(12): 1048-1077.

[24] 王胜鹏，宛晓春，林茂先，等. 基于水分、全氮量和粗纤维含量的茶鲜叶原料质量近红外评价方法[J]. 茶叶科学，2011，31(1)：

66-71.WANG S P,WAN X C,LIN M X,et al.Estimating the quality of tea leaf materials based on contents of moisture,total nitrogen and crude fiber by NIR-PLS techniques[J].Journal of tea science,2011,31(1):66-71(in Chinese with English abstract).

[25] WANG S P,ZHANG Z Z,NING J M,et al.Back propagation-artificial neural network model for prediction of the quality of tea shoots through selection of relevant near infrared spectral data via synergy interval partial least squares[J].Analytical letters,2013,46(1):184-195.

[26] 王胜鹏,龚自明,高士伟,等.近红外光谱结合神经网络判别茶鲜叶产地[J].中国计量学院学报,2014,25(4):419-423.WANG S P,GONG Z M,GAO S W,et al.Discrimination of the geographical origin of fresh tea leaves based on near infrared spectra and artificial neural network models[J].Journal of China University of Metrology,2014,25(4):419-423(in Chinese with English abstract).

[27] WANG S P,GONG Z M,SU X Z,et al.Estimating the acquisition price of Enshi yulu young tea shoots using near-infrared spectroscopy by the back propagation artificial neural network model in conjunction with backward interval partial least squares algorithm[J].Journal of applied spectroscopy,2017,84(4):704-709.

[28] ABDELKADER M F,COOPER J B,LARKIN C M.Calibration transfer of partial least squares jet fuel property models using a segmented virtual standards slope-bias correction method[J].Chemometrics and intelligent laboratory systems,2012,110(1):64-73.

[29] 王胜鹏,龚自明,卢素芳,等.基于近红外光谱技术的多品种茶鲜叶品质预测模型传递系统[CP].2019SR0054810.WANG S P,GONG Z M,LU S F,et al.Transfer system of fresh leaf quality prediction model for multi variety tea based on near infrared spectroscopy[CP].2019SR0054810(in Chinese).

[30] 龚自明,王胜鹏,滕靖,等.一种近红外光谱快速判定不同土壤类型茶鲜叶的方法:CN106442400B[P].2019-06-14.GONG Z M,WANG S P,TENG J,et al.A method for rapid determination of fresh leaves in different soil types by near infrared spectroscopy:CN106442400B[P].2019-06-14(in Chinese).

[31] 王胜鹏,龚自明,郑鹏程,等.一种近红外光谱判别不同栽培环境同一品种茶鲜叶的方法:CN106442399B[P].2017-02-22.WANG S P,GONG Z M,ZHENG P C,et al.Method for distinguishing fresh leaves of same variety of tea from different cultivation environments by aid of near infrared spectra:CN106442399B[P].2017-02-22(in Chinese).

[32] CHEN Q S,ZHAO J W,LIU M H,et al.Determination of total polyphenols content in green tea using FT-NIR spectroscopy and different PLS algorithms[J].Journal of pharmaceutical and biomedical analysis,2008,46(3):568-573.

[33] 任广鑫,张正竹,宁井铭,等.基于ATR校正的红茶成分近红外光谱无损检测[J].光谱实验室,2012,29(4):2148-2154.REN G X,ZHANG Z Z,NING J M,et al.Non-destructive NIR spectra measurement of black tea components based on ATR calibration[J].Chinese journal of spectroscopy laboratory,2012,29(4):2148-2154(in Chinese with English abstract).

[34] CHEN Q S,ZHAO J W,GUO Z M,et al.Determination of caffeine content and main catechins contents in green tea (*Camellia sinensis* L.) using taste sensor technique and multivariate calibration[J].Journal of food composition and analysis,2010,23(4):353-358.

[35] 徐荣荣,任广鑫,王胜鹏,等.样品形态对绿茶品质成分近红外定量预测的影响[J].食品工业科技,2012,33(14):72-75,79.XU R R,REN G X,WANG S P,et al.Influence of sample shape on the quantitative prediction of the quality components in green tea by near infrared spectroscopy (NIRS)[J].Science and technology of food industry,2012,33(14):72-75,79(in Chinese with English abstract).

[36] GUO Z M,CHEN Q S,CHEN L P,et al.Optimization of informative spectral variables for the quantification of EGCG in green tea using Fourier transform near-infrared (FT-NIR) spectroscopy and multivariate calibration[J].Applied spectroscopy,2011,65(9):1062-1067.

[37] SCHULZ H,ENGELHARDT U H,WEGENT A,et al.Application of near-infrared reflectance spectroscopy to the simultaneous prediction of alkaloids and phenolic substances in green tea leaves[J].Journal of agricultural and food chemistry,1999,47(12):5064-5067.

[38] LUYPAERT J,ZHANG M H,MASSART D L.Feasibility study for the use of near infrared spectroscopy in the qualitative and quantitative analysis of green tea,*Camellia sinensis* (L.)[J].Analytica chimica acta,2003,478(2):303-312.

[39] 徐立恒,吕进,林敏,等.茶叶中3类主要组分的近红外光谱分析作为茶叶质量的快速评定方法[J].理化检验-化学分册,2006,42(5):334-336.XU L H,LU J,LIN M,et al.Nir spectrometric analysis of 3 kinds of main components in tea as a rapid method of qualification of tea[J].Physical testing and chemical analysis (part B:chemical analysis),2006,42(5):334-336(in Chinese with English abstract).

[40] 王毅,陈斌,叶静,等.优化茶多酚近红外光谱定量分析模型[J].计算机与应用化学,2010,27(5):686-690.WANG Y,CHEN B,YE J,et al.Optimization on quantitative analysis models of tea polyphenols by near infrared spectroscopy[J].Computers and applied chemistry,2010,27(5):686-690(in Chinese with English abstract).

[41] 赵杰文,郭志明,陈全胜.基于OSC/PLS的茶叶中EGCG含量的近红外光谱法测定[J].食品与生物技术学报,2008,27(4):12-15.ZHAO J W,GUO Z M,CHEN Q S.Near infrared spectroscopy determination of EGCG content in tea based on OSC and PLS[J].Journal of food science and biotechnology,2008,27(4):12-15(in Chinese with English abstract).

[42] 陈全胜,郭志明,赵杰文,等.基于净分析物预处理算法的绿茶中儿茶素的近红外光谱定量分析[J].红外与毫米波学报,2009,28(5):357-361.CHEN Q S,GUO Z M,ZHAO J W,et al.Quantitative analysis of the catechins contents in green tea

with near infrared spectroscopy and net analyte preprocessing algorithm[J].Journal of infrared and millimeter waves,2009,28(5):357-361(in Chinese with English abstract).

[43] 耿响,陈斌,叶静,等.茶叶咖啡碱近红外光谱模型简化方法[J].农业工程学报,2009,25(10):345-349.GENG X,CHEN B,YE J,et al.Simplification of model for tea caffeine detection by near infrared spectroscopy[J].Transactions of the Chinese society of agricultural engineering,2009,25(10):345-349(in Chinese with English abstract).

[44] HALL M N,ROBERTSON A,SCOTTER C N G.Near-infrared reflectance prediction of quality,theaflavin content and moisture content of black tea[J].Food chemistry,1988,27(1):61-75.

[45] 阎守和,NABILA A.用化学分析结合主因素分析阐明感官审评[J].上海茶叶,2005(2):18-20. YAN S H,NABILA A. Chemical analysis combined with principal components analysis to approach sensory evaluation [J]. Shanghai tea industry,2005(2):18-20(in Chinese).

[46] 阎守和.应用近红外光谱法(NIRS)评估茶的品质及其商品价[J].上海茶叶,2005(4):20-22. YAN S H. Evaluate quality and commodity price of tea by using Near infrared spectroscopy(NIRS) [J]. Shanghai tea industry,2005(4):20-22(in Chinese).

[47] 周小芬,叶阳,周竹定,等.基于近红外光谱法的大佛龙井茶品质评价研究[J].光谱学与光谱分析,2012,32(11):2971-2975. ZHOU X F,YE Y,ZHOU Z D,et al.Study on quality evaluation of dafo Longjing teaand based on near infrared spectroscopy[J].Spectroscopy and spectral analysis,2012,32(11):2971-2975(in Chinese with English abstract).

[48] CHEN Q S,ZHAO J W,FANG C H,et al.Feasibility study on identification of green,black and Oolong teas using near-infrared reflectance spectroscopy based on support vector machine (SVM)[J].Spectrochimica acta part A:molecular and biomolecular spectroscopy,2007,66(3):568-574.

[49] CHEN Q S,ZHAO J W,ZHANG H D,et al. Qualitative identification of tea by near infrared spectroscopy based on soft independent modelling of class analogy pattern recognition [J]. Near infrared spectroscopy,2005,13(6):327-332.

[50] 赵杰文,陈全胜,张海东,等.近红外光谱分析技术在茶叶鉴别中的应用研究[J].光谱学与光谱分析,2006,26(9):1601-1604. ZHAO J W,CHEN Q S,ZHANG H D,et al.Study on the identification of tea using near infrared reflectance spectroscopy [J].Spectroscopy and spectral analysis,2006,26(9):1601-1604 (in Chinese with English abstract).

[51] WANG X,HUANG J H,FAN W,*et al*. Dentification of green tea varieties and fast quantification of total polyphenols by near-infrared spectroscopy and ultraviolet-visible spectroscopy with chemometric algorithms[J]. Analytical methods,2015,7(2):787-792.9):1601-1604(in Chinese with English abstract).

[52] 牛智有,林新.茶叶定性和定量近红外光谱分析方法研究[J].光谱学与光谱分析,2009,29(9):2417-2420. NIU Z Y,LIN X. Qualitative and quantitative analysis method of tea by near infrared spectroscopy [J]. Spectroscopy and spectral analysis,2009,29(9):2417-2420(in Chinese with English abstract).

[53] 李晓丽,何勇,裘正军. 一种基于可见-近红外光谱快速鉴别茶叶品种的新方法[J]. 光谱学与光谱分析,2007,27(2):279-282. LI X L,HE Y,QIU Z J. Application PCA-ANN method to fast discrimination of tea varieties using visible/near infrared spectroscopy [J]. Spectrosc Spect Anal,2007,27(2):279-282 (in Chinese with English abstract).

[54] REN G X,WANG S P,NING J M,et al. Quantitative analysis and geographical traceability of black tea using Fourier transform near-infrared spectroscopy (FT-NIRS) [J]. Food Res Int,2013,53(2):822-826.

[55] DINIZ P H G D,GOMES A A,PISTONESI M F,et al. Simultaneous classification of teas according to their varietiesand geographical origins by using NIR spectroscopy and SPA-LDA [J]. Food analytical methods,2014,(7):1712-1718.

[56] 陈全胜,赵杰文,张海东,等. 基于支持向量机的近红外光谱鉴别茶叶的真伪[J]. 光学学报,2006,26(6):933-937. CHEN Q S,ZHAO J W,ZHANG H D,et al. Indentification of authenticity of tea with near infrared spectroscopy based on support voctor machine [J]. Acta optica sinica,2006,26(6):933-937 (in Chinese with English abstract).

[57] YAN S M,LIU J P,XU L,et al. Rapid discrimination of the geographical origins of an oolong tea (anxi-tieguanyin) by near-infrared spectroscopy and partial least squares discriminant analysis [J]. J analytical methods chemistry,2014,2014:1-8.

[58] XU L,SHI P T,FU X S,et al. Protected geographical indication identification identification of a Chinese green tea (anji-white) by near-infrared spectroscopy and chemometric class modeling techniques [J]. J Spectrosc,2013,2013:1-9.

[59] LI X L,HE Y,WU C Q,et al.Nondestructive measurement and fingerprint analysis of soluble solid content of tea soft drink based on Vis/NIR spectroscopy[J].Journal of food engineering,2007,82(3):316-323.

[60] LIU F,YE X J,HE Y,et al. Application of visible/near infrared spectroscopy and chemometric calibrations for variety discrimination of instant milk teas [J]. Journal of food engineering,2009,93(2):127-133.

[61] HUANG J,REN G X,SUN Y M,et al.Qualitative discrimination of Chinese Dianhong black tea grades based on a handheld spectroscopy system coupled with chemometrics[J].Food science & nutrition,2020,8(4):2015-2024.

[62] SUN Y M,WANG Y J,HUANG J,et al. Quality assessment of instant green tea using portable NIR spectrometer[J/OL]. Spectrochimica acta part A:molecular and biomolecular spectroscopy,2020,240:118576[2021-05-01]. https://doi.org/10.1016/j.saa.2020.118576.

[63] WANG Y J,LI T H,LI L Q,et al.Micro-NIR spectrometer for quality assessment of tea:comparison of local and global models[J/OL].Spectrochimica acta part A:molecular and biomo-

lecular spectroscopy,2020,237:118403[2021-05-01]. https://doi.org/10.1016/j.saa.2020.118403.

[64] WANG J J,ZAREEF M,HE P H,et al.Evaluation of matcha tea quality index using portable NIR spectroscopy coupled with chemometric algorithms[J].Journal of the science of food and agriculture,2019,99(11):5019-5027.

Progress of using near infrared spectroscopy in tea

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Abstract The traditional sensory evaluation and wet chemical detection of tea quality have limitations including strong subjectivity,time-consuming and laborious determination. As a new type of analytical technique,near infrared spectroscopy has the advantages of fast,non-destructive,and objective results,and has been widely used in tea. Based on introducing the principle of near-infrared spectroscopy technology,this article mainly reviewed the use of near infrared spectroscopy in analyzing the quality of tea fresh leaves,detecting component,identifying tea grade and tea species,tracing tea geography and analyzing tea products deeply processed. The problems in using near-infrared spectroscopy technology in tea are analyzed. Some targeted countermeasures were proposed. It is expected that near infrared spectroscopy technology can provide solid scientific and technological support for the development of tea industry.

Keywords near infrared spectroscopy; tea; quality analysis; grade evaluation; type identification; geographical traceability of tea; analysis of tea deep processing products

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