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Process analysis for grain flow segregation on a combine harvester

In addition to quantitative yield variation, grain shows distinct quality variation depending on small scale heterogeneity as well as crop management. The aim of this collaborative research project is to analyze grain quality with near-infrared-spectroscopy (NIRS) and to sort grain based on defined quality values during harvesting. Since quality is an essential attribute of agricultural products and production processes the possibility of measuring grain quality parameters and separating the grain flow according to defined properties set the stage for implementing the technique of differential grain harvest as part of a quality assurance system.

Keywords

Near-infrared-spectroscopy (NIRS), grain flow separation, combine harvester, multivariate process control charts (MPCC)

Abstract

Landtechnik 65 (2010), no. 1, pp. 34-37, 1 table, 2 figures, 5 references

Within-field variability of grain quality is mainly correlated with spatial soil heterogeneity and crop management. Grain protein concentration is an important determinant of wheat and malting barley quality and thus the economic value of these cereal commodities. Protein mapping has widespread use for the documentation of spatial variation of grain quality. Near Infrared Spectroscopy (NIRS) has proved to be successful for this purpose. Research projects in Europe, the US and Australia have investigated the protein mapping approach in detail. Real-time analysis and mapping of crude protein concentration mainly deal with providing appropriate sensor systems, their calibration, protein mapping and variable rate nitrogen applications.

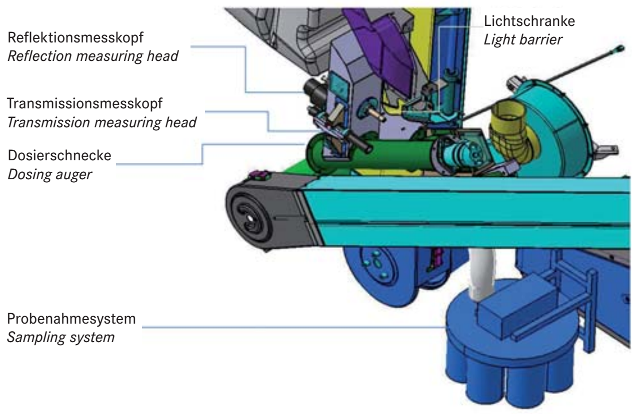
The study described herein examines the potential of segregation of grain by protein concentration into fractions of high and low quality on a combine harvester. This harvesting technique is based on NIRS real-time analysis of grain quality. The feasibility of segregating different qualities of grain during harvesting has been described in several publications. The process-engineering principles of this harvesting technique were described in previous studies [1; 2].

Sorting of grain on-combine requires fast and accurate analysis of protein and moisture content for real-time sensor-actuator interaction. Automated sampling serves to gain retain samples for the calibration and validation of NIRS sensors. Reference values provide the definition of sample properties and help to extend and validate laboratory calibrations. The Department of Biosystems Engineering of the Humboldt-Universität zu Berlin and CLAAS SE GmbH are developing a harvesting technique for the segregation of grain according to defined quality parameters during harvesting in a collaborative research project.

Experimental Setup

The experimental setup consists of following modifications of the combine harvester: clean grain elevator/the filling auger and grain tank assemblies. A bypass equipped with a reflection measuring sensor head and a second bypass equipped with a transmission measuring sensor head are mounted to the side of the grain elevator. The separated grain flow is led past the relevant probes. Fibre optic cables are connecting the sensor heads and the spectrometer in the combine's cab. A near-infrared spectrometer (NIRS), recording reflection spectra in the wavelength range from 960 to 1,690 nm and transmission spectra in the wavelength range from 400 to 1,100 nm, was used to measure spectral data of winter wheat and spring barley in both diffuse reflection and diffuse transmission. A dosing auger conveys the detected grain flow back to the elevator and is also used to fill the laboratory sample flasks of the sampling system (**figure 1**).

Fig. 1



Experimental setup: sensor heads mounted to elevator bypass of Claas Lexion 570 combine harvester

The spectrometer software is logging both spectral data and analysis values. After conversion, the protein measurement values are used to switch a hydraulically operated gate in order to direct the grain flow into the certain part of the twin grain tank system. Both grain tank chambers can be emptied separately. Spectral and analytical data logging is monitored using a light barrier sensor. Thus, a continuous measurement can be interupted as soon as the grain flow in the bypass is decreasing. During evaluation, different filters are used in order to exclude redundant and non-relevant information from data analysis. Reference values provide the definition of sample properties and help to extend and validate laboratory calibrations.

Field experiments were conducted in Brandenburg (Landwirtschaft Golzow Betriebs-GmbH) and Thuringia (Thüringische Lehr-, Prüf und Versuchsgut GmbH, Buttelstedt). The tec5 Agrospec NIRS spectrometer is recording reflection spectra in the wavelength range from 960 to 1,690 nm and transmission spectra in the wavelength range from 400 to 1,100 nm. The spectrometer software is logging spectral data and analysis values.

NIRS and automated sampling system

First, the sensor system was tested in the laboratory for stationary evaluation and calibration development. The calibration data set consists of 518 wheat and barley samples of 30 varieties from 18 different growing areas to obtain robust calibration models for the prediction of crude protein and moisture content. These laboratory calibration models were continuously validated during field trials in the 2008 and 2009 grain harvest. Long-term stability of calibration is achieved by monitoring the biased error, the prediction intervall and the leverage.

Tab. 1

Predicted crude protein and prediction intervall yDev for spring barley (Hordeum vulgare), breed Christina, 22 ha, Thüringen 2008

Proben Nr. *Sample No.*	Vorhergesagter Rohproteingehalt *Predicted crude protein [%]*	Vorhersage-bereich Ydev *Prediction intervall* [%]*	Referenzwert *Refrence value* [%]
71	11.129	0.280	11.649
72	10.603	0.259	10.648
73	10.819	0.260	10.515
74	10.335	0.299	10.317
75	10.081	0.297	10.054
78	9.297	0.299	9.268
79	10.685	0.213	10.618
80	10.425	0.314	10.389
81	10.712	0.216	10.767
82	10.261	0.199	10.091
83	10.205	0.276	11.173
84	9.555	0.328	9.033
85	9.923	0.246	10.365
86	10.015	0.206	9.715
87	10.389	0.219	10.266
88	10.564	0.215	10.560
89	10.033	0.296	9.838
90	10.604	0.188	11.045
91	10.486	0.159	10.605
92	10.317	0.500	10.431
93	10.643	0.218	10.785
94	9.811	0.421	9.816
95	10.372	0.323	11.301
96	10.340	0.335	10.323
97	10.578	0.244	10.578
98	10.176	0.204	10.328
Mittelwert	10.321	0.270	10.403

* Standard Error of Prediction (SEP) = 0,369 %

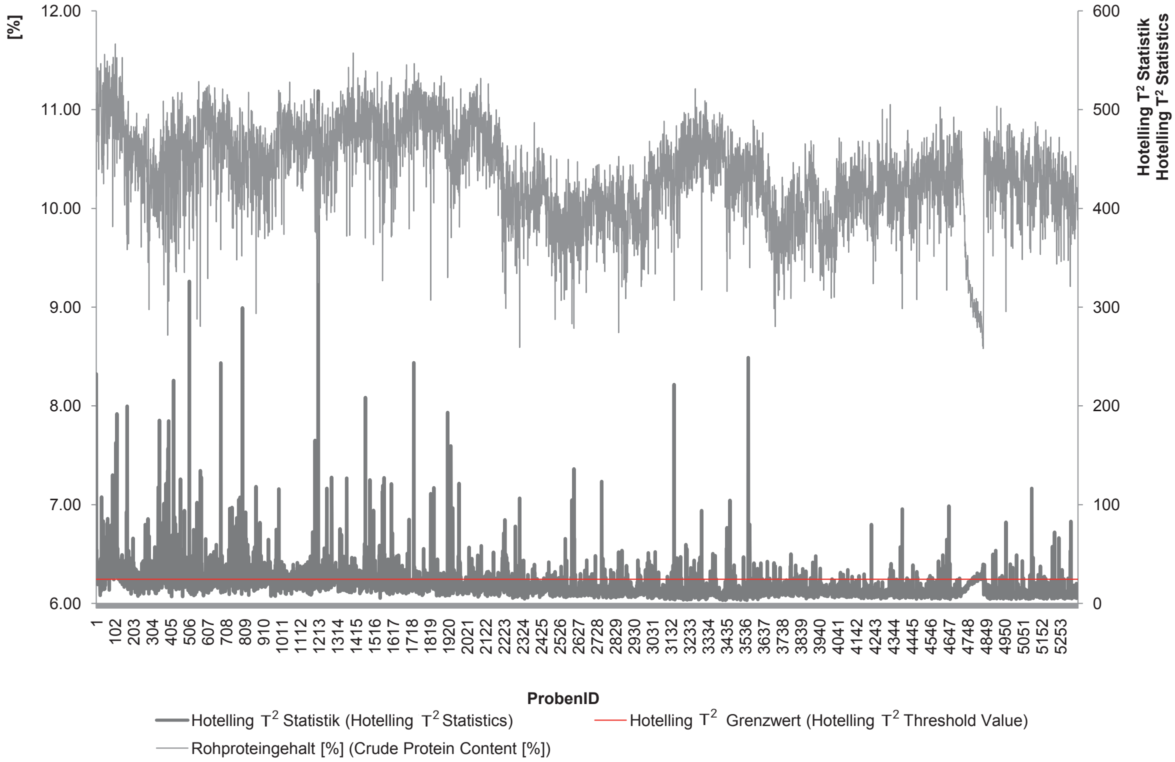
According to EU regulation 178/2002, it is necessary to consider all aspects of the food production chain as a continuum from and including primary production in order to ensure the safety of food. This also includes the production of animal feed up to and including sale or supply of food to the consumer because each element may have a potential impact on food safety. These demands result in the necessity of continuous grid grain sampling. In order to keep information-logistic needs and potential delays during the harvest process chain to a minimum, it is absolutely necessary to automate sampling itself as well as marking and data backup. In the collaborative project described here, the sampling system is used on the experimental machine for the quality-differentiating grain harvest in order to gain reference samples for the calibration and validation of the installed NIRS sensor technology. Depending on the throughput and the position of the combine, sampling is acivated manually as required.

Data analysis

In process analytics, data analysis is essential for the evaluation of the multidimensional information matrices. According to Kessler [3], the main aspects of data analysis are the separation of overlapping information, the exclusion of redundant information, the reduction of the dimensions of information, the exclusion of non-relevant information, as well as the storage and presentation of knowledge. Multivariate Process control charts (MPCC) are used to detect shifts in the mean or the relationship (covariance) between several related parameters. MPCC are particularly suitable for the characterization of processes due to the option to analyze correlated variables and to provide improved tools for error diagnosis. In order to detect spectral outlier values and to signify instabilities in the process, the process data are classified using principal component analysis (PCA). The prediction range of the crude protein values, leverage, and the hotelling T^2 statistics are recorded continuously [4].

The T^2 control chart, based upon Hotelling's T^2 statistic, is used to detect shifts in the process. Instead of using the raw process variables, the T^2 statistic is calculated for the process' Principal Components, which are linear combinations of the Process Variables [5]. Multivariate control charts are based on the definition of a target value (stable, optimal process conditions), which should be kept constant during the entire analysis and separation process. MSPC is therefore particularly suitable for the characterization and the diagnosis of spectral deviation. The distribution of measured crude protein (XP) values (%) and the corresponding standard deviation are shown in **table 1**. During the trial, a total of 26 reference samples were taken and compared to predicted values. Deviations of NIRS analysis results beyond the calibration error of 0.37% are continuously logged and shown in the hotelling T^2 plot (**figure 2**).

Fig. 2



Hotelling T^2 Statistics and hotelling T^2 threshold value = 24.436, spring barley (Hordeum vulgare), breed Christina, 22 ha, Thüringen 2008

Conclusions

Results show that the established technique of near-infrared spectroscopy is suitable both for real-time analysis of grain quality on-Combine and for grain flow control based on defined quality thresholds. The analysis of deviation of predicted protein content, yDeviation as an estimator of the actual crude protein prediction and hotelling T^2 statistics indicate that deviations are primarily caused spectral deviation. Spectral data logging under constant, optimized conditions required in laboratory and in the application of PAT in the pharmaceutical industry cannot be guaranteed in field use. Spectral deviations should be recorded and analyzed continuously in order to avoid errors in the predicted values which lead to incorrect grain tank filling. The stability of on-line analysis and the separation of the grain flow according to defined parameters require continuous monitoring of additional process parameters.

Monitoring of process parameters which influence process analytics is essential for the stability of online analysis and the separation of the grain flow based on defined parameters. This includes the monitoring of physical quality parameters, such as particle size, thousand grain mass, kernel damage, impurities, and colour alterations with imaging techniques that could be applied in addition to the monitoring of the machine settings. Imaging techniques in combination with NIRS are also expected to be applicable for the online analysis of fusarium and mycotoxin contamination in future.

In future, the inline analysis of grain quality parameters could be combined with yield monitoring systems with further development of NIR spectrometers. Since quality is an essential attribute of agricultural products and production processes in particular as a result of European Commission (EC) directives, the possibility of measuring grain quality parameters and separating the grain flow according to defined properties set the stage for implementing the technique of differential grain harvest as part of a quality assurance system.

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