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IR radiation method in moisture testing of various types of grains

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ABSTRACT

The aim of the research was to compare the possibilities of using various research techniques to determine the moisture content of wheat, barley and corn. The research material consisted of grain samples collected immediately after 2022 harvest from various climatic and cultivation areas located in Poland. Grain moisture content was determined using a grain moisture meter (GAC), NIR analyzer, and moisture analyzer (MA). The research cycle of the NIR and GAC methods was known, as they are normative methods. The result of the MA method was strongly dependent on the wavelength of the emitter's IR radiation, therefore, through a series of studies, the parameters of this method were correlated to obtain a result consistent with the results of normative methods. This approach is mandatory for each type of grain and takes into account the reaction of the components constituting the sample, its degree of fragmentation and the transmission of mass and heat in the structure of the sample when it is heated. The moisture content in the grain varied depending on the type of grain, the research method used and the climatic and cultivation area. The highest moisture content was found in corn grain, on average 31.42 ± 6.83%, and the lowest moisture content was found in wheat grain, 12.60 ± 5.05% and barley grain, 12.81 ± 0.88%. It was found that the precision of the moisture results of the optimized MA method depended on the climatic and cultivation area from which the grain samples were taken for testing. The MA method can be used instead of the NIR and GAC methods, maintaining the appropriate research procedures.

Keywords: grains quality, moisture meters analyzer, infrared heating, NIR technology, moisture analyzer.

INTRODUCTION

Agriculture plays a key role in the economy, providing raw materials for both direct consumption and industrial processing. Cereals are a strategic resource used in food, feed, and the production of bioethanol or biodegradable fillers. Their quality is primarily determined by variety but is also strongly influenced by agronomic practices, soil conditions, and climate. A critical factor affecting cereal quality is the water content in the grain. Uneven rainfall, drought, and biotic or abiotic stresses can reduce yields, negatively impacting grain quality and its potential applications. Maintaining proper moisture levels is essential, as deviations can lead to degradation, spoilage, and loss of economic value.

Excessive moisture in grain promotes degradation and can favor the development of fungi and molds. Since grain is bought and sold by weight, even minor changes in water content can lead to significant economic gains or losses. This is particularly important in trade, considering that recent years have seen annual cereal production in Poland exceed 26 million tons [1]. Grain with too high water content must be dried to the appropriate level, which increases costs. However, over-drying can cause cracks and result in losses during reloading [2]. The ideal moisture content is generally within the range of 13–14% [3–4]. Therefore, testing the water content is essential in every transaction.

The determination of moisture content in materials is governed by internationally recognized standards that ensure accuracy and reproducibility of results. In the context of grain moisture content determination, several standardized methods are widely recognized. The Near-Infrared Spectroscopy (NIR) method follows the EN 15948:2020 standard [5], which specifies the procedure for determining moisture and protein in cereals using whole kernels. Additionally, the capacitive method using grain moisture meters adheres to ISO 7700-1:2008 [6], which outlines the performance checks for moisture meters in cereals. The reference method for moisture content determination in cereals and cereal products is detailed in EN ISO 712:2009 [7], ensuring accurate and reliable results.

Several methods are used to measure water content in grains, with varying degrees of complexity. Fast indirect methods, such as electrical and optical techniques, measure physical parameters and predict moisture content using equations or calibration charts. These methods are quick but may lack precision. On the other hand, reference methods based on mass loss during heating require more time (about several hours) but are more accurate [7–8]. These methods are usually impractical when quick results are required, highlighting the need for efficient alternatives. More efficient methods are needed to balance accuracy, cost, and speed.

Recent engineering studies emphasize that the optimization of measurement and production processes – whether in structural stability testing of materials or in hybrid manufacturing – requires a careful balance between efficiency, reliability, and cost-effectiveness [9–10]. Insights from such interdisciplinary approaches may inform the development of improved grain moisture determination techniques as well.

Choosing the right method is crucial for business management, as it can lead to both financial savings and increased efficiency. In this study, the water content of selected grains was analyzed, and various methods were evaluated in terms of efficiency, accuracy, and precision. Devices such as the NIR near-infrared analyzer [5], grain moisture meter [6], and moisture analyzer were used to measure the water content in barley, wheat, and corn.

One of the goals of this work was to demonstrate that a non-normative method, the moisture analyzer (MA), can be effectively applied in grain moisture studies. To validate this, normative information on grain moisture content was obtained using methods such as NIR and GAC. Optimizing the MA method involved defining its parameters and proving through comparative studies that they were appropriately chosen.

MATERIAŁ AND METHODS

Material

The research material consisted of samples of barley, wheat and corn grain obtained during the 2022 harvest, taken from six (I – VI) climatic and cultivation regions of Poland (Figure 1). The samples came from commercial agricultural production and were delivered through Agricultural Advisory Centers as well as by grain elevators and companies processing grain. In the case of wheat and corn, 10 grain samples were taken from each region, from which analytical samples were then separated and subjected to water content tests. In the case of barley grain, the number of tested samples in a given region ranged from 5 to 10. The location of the growing regions in Poland is shown in Figure 1. The specifications of the tested samples are presented in Table 1.

Grain preparations and storage

Grain samples were delivered to the laboratory between October and November 2022. Prior to analysis, the samples were stored in a cold store to reduce the development of microorganisms and molds. Before testing, the samples were conditioned in the laboratory at a temperature of 20 ÷ 24.5 °C and relative humidity of 45 ÷ 50%. The temperature of the tested grain samples was in the range of 15 ÷ 18 °C.

Methods

Method using near infrared transmission

Moisture content of tested grain was determined using Near Infrared Transmission grain analyser XGrain (Infracont, Hungary) with the calibrations develops for Polish market. Infracont

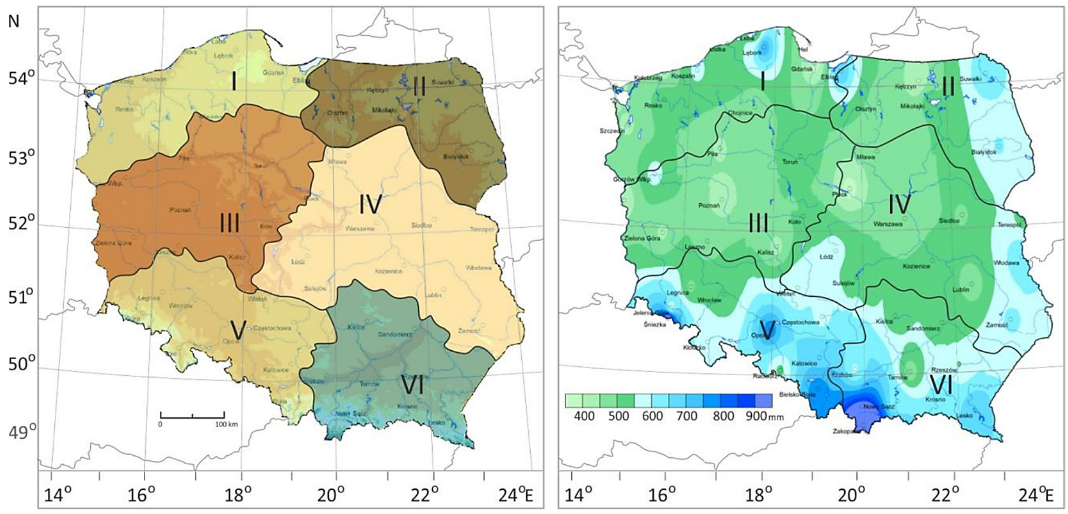

Figure 1. Climatic and cultivation area (I ÷ VI) according to Research Centre for Cultivar Testing (COBORU) and total precipitation in Poland in 2022.

Table 1. The number and origin of grain samples tested in the study

Climatic and cultivation area according to COBORU	Number of tested samples		
	Wheat	Barley	Maize
I	10	5	10
II	10	10	10
III	10	10	10
IV	10	10	10
V	10	7	10
VI	10	5	10
TOTAL	60	47	60

grain analysers was developed in calibrations with Partial Least Squares (PLS) or MLR (Multiple Linear Regression) method, based on sample series analysed in laboratory. The principle of this method based on Near-Infrared (NIR) spectroscopy (Figure 2), an indirect, correlative technique to predict the concentration of various constituents in organic samples. Linear or nonlinear regression modelling is used to relate NIR spectra to moisture concentrations determined by officially approved standard methods (e.g. artificial neural network-ANN, Partial Least Square Regression – PLS).

NIR radiation was sent from the transmitter (1) to the measurement track containing the sample of the tested material (3). The structure of the sample partially absorbed the radiation, so the original NIR radiation signal was distorted into the NIR radiation spectrum. After absorbing the spectrum, its intensity was measured for several wavelengths of radiation using a monochromator with a scanning grating (5). Based on the light intensities measured by the photodiode and using the so-called calibration curves (6) XGrain presented the characteristics of the tested sample in terms of moisture content. The NIR method did not require sample fragmentation. Before starting the research, the calibration coefficients of the XGrain device were verified in relation to the grain moisture results from the 2022 harvest, which were obtained by testing grains using the reference method according to [7] (wheat and barley) and [8] (corn).

Method using grain moisture meter (GAC)

The water content determination using a GAC® 2100 moisture meter (Dickey-John®, USA) was based on the assumption that there is a defined relationship between the moisture content in the grain and its dielectric constant [9]. This relationship was described by a calibration curve adapted to a specific type of grain. During

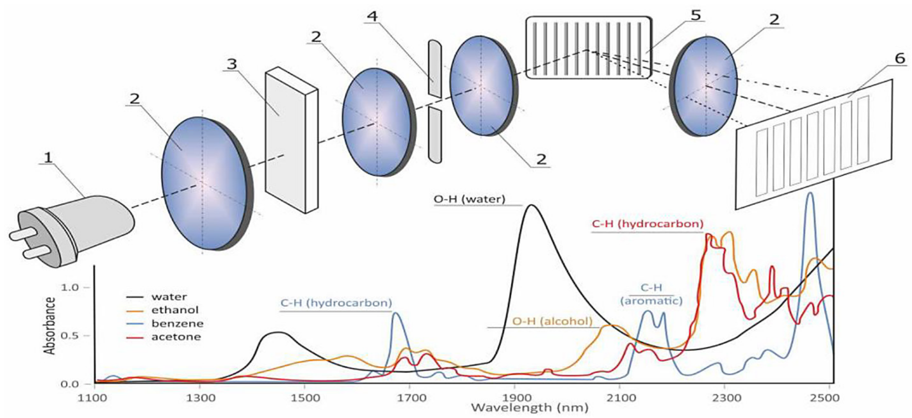

Figure 2. General diagram explaining on how NIR technology works. Legend: 1 – NIR LED, 2 – lens, 3 – sample, 4 – slit, 5 – greting, 6 – detector array (own work)

the measurement, the tested sample without fragmentation was placed in the measurement cell, which resulted in a change in the original electrical properties of the measurement system. The detection of changes in the electrical properties of the measurement system in relation to the calibration curve was sufficient to calculate the sample moisture by the GAC® 2100 moisture meter. The accuracy of the moisture determination for individual cereal grains was verified by comparing the moisture results of cereal grains obtained from the harvest in 2022 with the moisture results obtained by testing the same grains using the reference method according to [7] (wheat and barley) and [8] (corn).

Method using moisture analyzer (MA)

The method of testing the water content using a moisture analyzer (MA 50.X2, Radwag) consisted in recording the weight loss of a wet sample during its controlled heating. Before starting the analysis, the mass of the wet sample (1) that was placed in the drying chamber (4) was recorded (Figure 3). After drying began, the chamber together with the sample was heated by an IR radiator (2), which worked in feedback with the temperature sensor (3). The measurement of sample mass variability was recorded by the measurement system, in which the signal from the position sensor (5) and the processing system (6) was used by a magnetoelectric transducer (7) to generate a compensating signal to keep the measurement system in the equilibrium position. The accuracy of mass measurement was ensured by adjustment with an adjustment mass (8). During the analysis, the variability of the sample mass was recorded continuously. Based on the difference between the masses of the wet sample and the mass of the dry sample, the moisture analyzer recorded the sample moisture according to the relationship.

$$water\ content\ (\%) = 100\% \cdot \frac{m_{wet} - m_{dry}}{m_{wet}} \quad (1)$$

where: m_{wet} – mass of the test portion (grams); m_{dry} – mass of the test portion after drying (grams).

Before analysis, grain samples were mechanically crushed into small pieces in order to obtain a uniform drying temperature throughout the sample volume.

The measurement techniques described in this study are not novel but are recognized to the extent of their established applications. However, the notion of a "known measurement technique" does not imply that the analytical results obtained using such a technique are inherently accurate. This is particularly relevant in the case of the MA method, which involves the use of a moisture analyzer (drying balance). This method is not standardized, and consequently, there is no universally accepted testing procedure.

As is well known, moisture analyzers can be equipped with various types of heat sources, such as glass IR lamps, metal emitters, or metal emitters with ceramic shields, all of which emit infrared radiation at different wavelengths. The efficiency of grain drying is significantly affected by the wavelength of the emitted infrared radiation. Therefore, while drying using a moisture analyzer is a well-known technique, its application

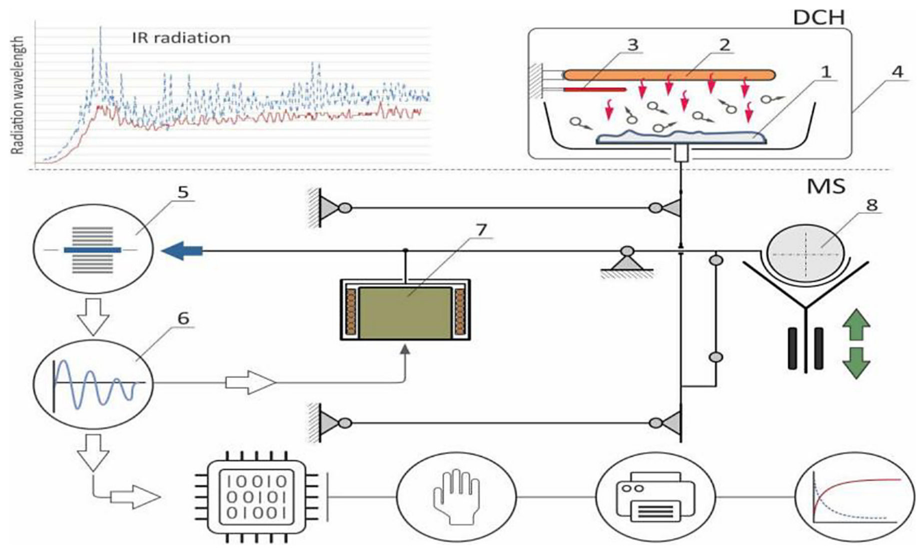

Figure 3. Diagram of the operating principle of the moisture analyzer

Note: DCH – drying chamber, MS – measuring system, 1 – tested sample, 2 – IR radiation emitter, 3 – temperature sensor, 4 – drying chamber, 5 – position sensor, 6 – element processing the measurement signal, 7 – electromagnetic transducer, 8 – adjustment mass.

requires validation against other methods recognized as reference standards.

Empirical evidence indicates that a lack of validation inevitably leads to erroneous results, as there is a common misconception that a "known method" is automatically accurate. In metrology, accuracy must be demonstrated through empirical research; theoretical assumptions are insufficient. In contrast, normative methods follow a defined procedure that has been verified through testing. In the case of the MA method utilizing a moisture analyzer, the optimal parameters must be empirically determined. Practical experience shows that these drying parameters vary depending on the type of heat emitter used in the moisture analyzer.

Statistical analysis

The accuracy of moisture determination in grains using the MA (moisture analyzer) method was compared to the results obtained using standard drying methods, i.e. grain moisture meter (GAC 2100) and NIR (XGrain). This activity was aimed at demonstrating whether the MA method can be used as an alternative method for cereal moisture testing. It was assumed that the reference value for assessing the systematic error of the MA method would be the sample moisture result obtained by the NIR method. The random error in measuring the water content of each method was determined by the standard deviation from a series of measurements, which was an indicator of the qualitative differentiation of grains as a result of the impact of biotic and abiotic stresses. The r-Pearson correlation coefficient was determined for the compared research methods. Moisture content results obtained using various methods were statistically estimated using a two-way analysis of variance (ANOVA) with a subsequent Tukey's HSD test at a significance level of $p < 0.05$, taking into account the moisture content method and cultivation area.

RESULTS AND DISCUSSION

The average moisture content of wheat grains determined by the NIR method ranged from 12.87% to 13.84%, which indicated little variation considering that the tests were performed for samples from six quite large cultivation regions. Similar values were obtained using the MA and GAC methods for determining moisture in grains, except that for the MA method based on sample mass loss, the systematic error of the moisture result had a negative value regardless of the climatic and cultivation region from which the samples were taken for testing. Such a relationship indicated the need to revalidate the research method or correct the humidity result by introducing a permanent correction. The largest systematic error of the capacitive method (GAC) was recorded for region III (-0.19%), for the remaining cultivation regions the systematic error had a significantly smaller value and was in the range of 0.01÷0.11% (Table 2). The standard deviation was a measure of the moisture uniformity of the grains. It was found that only wheat grains collected from regions II and III were homogeneous in terms of moisture content, regardless of the testing method used. The scatter of moisture measurements (Pmv) for grains from these climatic regions was in the range of 1.79÷4.16% of the measured value, and for the remaining growing regions, the random error in the series of measurements was significantly larger and ranged from 5.51% to 10.39% of the measured value (Table 2). These relationships were observed for each of the research methods used.

The moisture content of tested barley grain samples collected from six climatic and cultivation areas, determined using an NIR analyzer, was in the range of 11.87÷13.71%, which was an acceptable value for their processing and long-term storage [4]. The discrepancy in moisture results between growing regions was 1.84% for the NIR method, 1.88% for the MA method and 2.30% for the GAC method, which indicated that the observed discrepancies are not the result of the use of different research methods, but rather the differences in moisture content of samples between growing regions [10–11]. The systematic error of the MA and GAC methods compared to the NIR method was calculated as the difference between the average humidity values and did not exceed 0.33%. The magnitude and sign of the systematic error only for grains from region V were similar for the MA and GAC methods, 0.32% and 0.22%, respectively. For other cultivation areas, discrepancies in systematic error for these methods were recorded in terms of size and sign.

The moisture uniformity of barley grains for growing regions I, II, III, IV and V varied in terms of moisture content, even up to 1.30% (NIR method). This phenomenon was recorded in all measurement methods used, clearly indicating the need to condition grain as a necessary element in its processing chain [12–14]. The standard deviation of the moisture results, which is a measure of the moisture uniformity of barley [15], was the lowest, i.e. 0.50% for the MA method, sample from region VI. The maximum variation in this region was 3.87% of the measured value (Table 3). For other growing regions, the moisture content of barley samples was in the range of pprox. 4.75÷9.69%. It was found that the greatest discrepancies in the uniformity of grains occurred in regions I and III, where the sum of annual rainfall during grain vegetation was approximately 400–500 mm. These were regions of north-western and central Poland with similar terrain. Similar discrepancies were recorded for the cultivation region number V with the sum of annual rainfall of approximately 600 mm, but it should be noted that this area is located in south-western Poland and is dominated by mountainous terrain.

The moisture content of most tested maize grain samples was over 30% (Table 4), except for samples from the VI climatic and cultivation region (south-eastern part of Poland), which had a significantly lower moisture content, only about 22%. No significant differences were found

Table 2. Wheat moisture content, systematic error and measurement precision acc. to NIR, MA, GAC methods

CCA	NIR method		MA Moisture analyzer method		GAC Moisture Meter method	
	$\bar{x} \pm S$ (%)	P_{mv} (%)	$\bar{x} \pm S$ (%)	P_{mv} (%)	$\bar{x} \pm S$ (%)	P_{mv} (%)
I	12.87±1.30	10.10	12.61±1.31	10.39	12.98±1.34	10.32
II	13.28±0.44	3.31	13.00±0.37	2.85	13.23±0.55	4.16
III	13.43±0.24	1.79	12.17±0.36	2.96	12.24±0.40	3.27
IV	13.73±0.78	5.68	12.43±0.84	6.76	12.68±0.87	6.86
V	13.84±0.84	6.07	12.65±0.88	6.96	13.94±0.92	6.60
VI	13.03±0.83	6.37	12.71±0.70	5.51	13.05±0.91	6.97

CCA	I	II	III	IV	V	VI
Sys. err. NIR /MA	-0.26	-0.28	-0.26	-0.29	-0.19	-0.32
Sys. err. NIR/GAC	0.11	-0.05	-0.19	-0.04	-0.10	0.01

Note: CCA – climatic and cultivation area, S – standard deviation as precision of measurement, P_{mv} – measurement precision as a percentage of the measured value.

Table 3. Barley moisture content, systematic error and measurement precision acc. To NIR, MA, GAC methods

CCA	NIR method		MA Moisture analyzer method		GAC Moisture Meter method	
	$\bar{x} \pm S$ (%)	P_{mv} (%)	$\bar{x} \pm S$ (%)	P_{mv} (%)	$\bar{x} \pm S$ (%)	P_{mv} (%)
I	13.43±1.30	9.68	13.10±1.27	9.69	13.45±1.02	7.58
II	13.34±1.08	8.10	13.15±0.81	6.16	13.48±0.89	6.60
III	12.28±1.03	8.39	12.37±0.85	6.87	12.48±0.87	6.97
IV	12.20 ±0.58	4.75	12.28±0.36	2.93	11.8 ±0.75	6.32
V	13.71±0.98	7.15	14.03±1.15	8.20	13.9 ±1.05	7.54
VI	11.87±0.33	2.78	12.15±0.11	0.50	13.05±0.91	6.97

CCA	I	II	III	IV	V	VI
Sys. err. NIR /MA	-0.33	-0.19	0.09	0.06	0.32	0.24
Sys. err. NIR/GAC	0.02	0.14	0.20	-0.36	0.22	-0.24

Note: CCA – climatic and cultivation area, S – standard deviation as precision of measurement, P_{mv} – measurement precision as a percentage of the measured value.

between the moisture results obtained when analyzing maize samples using different methods. The largest systematic error, i.e. -3.67%, was recorded for the GAC capacitive method, when the analysis concerned samples taken from climatic and cultivation region IV. The average maize moisture results obtained using the capacitive method were significantly lower than the moisture results obtained using the NIR method. From the observation of the variability of the results, it can be concluded that the capacitive method shows better correlation than the NIR method at a lower humidity of the analyzed sample, which is approximately 20%. Such a phenomenon was not recorded for the MA method, the size and sign of the systematic error were not correlated with the humidity level of the analyzed sample. The standard deviation of moisture results, which is a measure of the moisture diversity of the tested samples, had quite high values for each of the methods used (Table 4). For the NIR method, the random error of moisture determination was in the range of 9.16÷30.48% of the determined value, for the MA method in the range of 12.98÷33.27%, and for the GAC capacitive method 9.48÷26.75%. Such a large dispersion of results in a series of measurements resulted from the structure of the tested sample, the genetic factor, the agrotechnics used and the climatic and soil conditions in which grain was grown [16-21]. It was found that the best uniformity of corn grains occurred in cultivation areas IV and V, where the discrepancy in grain moisture content results did not exceed 12.98% of the measured value (Table 4). In other cultivation areas, the moisture variation was even over 30%, corn grains from cultivation area II.

The r-Pearson correlation coefficient of the moisture results of the tested grains for the NIR/MA and NIR/GAC methods used was in the range of 0.90÷0.95 (wheat), 0.87÷0.92 (barley) and 0.80÷0.97 (maize), which indicated that the physical phenomena used in these research methods, i.e. gravimetric drying of the sample and change in dielectric properties, did not have a significant impact on the variation of results in a series of measurements. Each of these methods can be used when assessing grain moisture, but as noted earlier, correct correlation coefficients related to the type of grain being tested are necessary for the capacitive (GAC) method and the NIR method. In the case of a method based on weight loss as a result of drying (MA), it is necessary to optimize it as part of the validation process for a given type of grain.

The statistical results for the carried out moisture tests of wheat, barley and maize grain samples are presented in Table 5. There were no statistically significant interactions between the moisture results when the NIR, GAC and MA methods were used. The physical phenomena used in these research methods, such as the IR radiation spectrum, change in the resistance of the measurement system and controlled mass loss as a result of heating the grain sample, did not have a significant impact on the differences in humidity results. The observed differences in grain moisture were the result of different climatic and cultivation conditions that occurred in Poland in 2022.

Table 4. Maize – moisture content, systematic error and measurement precision acc. to NIR, MA, GAC methods

CCA	NIR method		MA Moisture analyzer method		GAC Moisture Meter method	
	$\bar{x} \pm S$ (%)	P_{mv} (%)	$\bar{x} \pm S$ (%)	P_{mv} (%)	$\bar{x} \pm S$ (%)	P_{mv} (%)
I	31.35±8.36	26.67	31.58±7.49	23.72	29.32±6.21	21.18
II	31.20±9.51	30.48	32.67±10.87	33.27	29.53±7.90	26.75
III	32.85±6.81	20.73	34.22±8.01	23.41	31.93±5.16	16.16
IV	36.77±3.37	9.17	37.51±4.63	12.34	33.10±3.14	9.49
V	32.10±3.98	12.40	31.13±4.04	12.98	31.04±3.53	11.37
VI	22.14±5.70	25.75	21.40±5.94	27.76	22.33±4.34	19.44

CCA	I	II	III	IV	V	VI
Sys. err. NIR /MA	0.23	1.47	1.37	0.74	-0.97	-0.74
Sys. err. NIR/GAC	-2.03	-1.67	-0.92	-3.67	-1.06	0.19

Note: CCA – climatic and cultivation area, S – standard deviation as precision of measurement, P_{mv} – measurement precision as a percentage of the measured value.

Table 5. Moisture content of grain tested by different methods

Factor		Moisture content (%)	
Type of grain	Wheat	Barley	Maize
		Type of method	
NIR analyzer	12.86b ± 0.74	12.81 ± 0.88	31.07ab ± 6.29
GAC - Moisture meter	12.85b ± 0.83	12.80 ± 0.84	29.51a ± 5.27
MA - Moisture analyzer	12.59a ± 0.75	12.84 ± 0.76	31.42b ± 7.19
Climatic and cultivation area			
I	12.82bc ± 1.28	13.33bc ± 1.11	31.11b ± 8.10
II	13.17c ± 0.46	13.32b ± 0.90	31.31b ± 9.25
III	12.27a ± 0.36	12.37a ± 0.89	33.30bc ± 6.70
IV	12.61ab ± 0.81	12.12a ± 0.60	36.20c ± 3.85
V	12.80bc ± 0.86	13.89c ± 1.00	32.34b ± 4.21
VI	12.93bc ± 0.80	11.88a ± 0.41	22.00a ± 5.21

Note: a, b, c, d – values marked with the same letters do not differ significantly at $p < 0.05$; s – standard deviation.

The differences in humidity results between the cultivation regions observed during the research were the result of the water shortage that occurred in Poland in 2022. According to information from the Institute of Soil Science and Plant Cultivation State Research Institute in Puławy [22], the climatic water balance for the area of Poland was negative in 2022, which means the occurrence of drought in large cultivated areas. The area-averaged sum of precipitation in 2022 in Poland amounted to 534.4 mm, which was only 87.4% of the norm determined on the basis of measurements in 1991–2020.

The cereal grain moisture results obtained in this study are consistent with the results of research carried out in works on the assessment of the technological value of grain from commercial agricultural production in Poland [23]. The moisture content of wheat grains from the 2022 harvest in Poland ranged from 9.6 to 18.3% (average 13.0%), barley grains from 10.4 to 16.1%, and corn grains from 10.4 to 50.1%.

It should be noted that the final moisture content of maize grain harvested from the field is on average about 10% higher than the moisture content of ear cereal grains. The climatic conditions in Poland mean that at the time of harvesting, maize grain has a significant moisture content of approximately 30–38%, which was also confirmed in the research presented in this work.

CONCLUSIONS

Determination of the moisture content of cereal grains can be performed using methods of varying degrees of complexity, but it should be noted that each of them should provide accurate results, i.e. results that can be the basis for technological and economic activities. The NIR method used in the research had the normative reference EN 15948:2020 – Cereals – Determination of moisture and protein – Method using Near-Infrared-Spectroscopy in whole kernels. The standard for the capacitive GAC method was ISO 7700-1:2008 Food products – Checking the performance of moisture meters in use – Part 1: Moisture meters for cereals. However, it should be clearly stated that the accuracy of these methods was significantly dependent on correlation coefficients related to the type of sample analyzed. From a metrological point of view, the correctness of these coefficients should be periodically verified in comparison to other reference methods. If significant differences occur, it is necessary to correct the NIR or capacitive method. Such activities are possible for personnel equipped with knowledge and appropriate research equipment, which is not common in the area of grain quality supervision. The parameters of the method (MA) based on mass loss are always optimized as a result of validation against recognized standards, e.g. EN-ISO 712:2009 Cereals and cereal products – Determination of moisture content – Reference method, EN ISO 6540:2021 Maize – Determination of moisture content (on milled grains and on whole grains). Maintaining appropriate research procedures always guarantees the correctness of the obtained results, which the authors also achieved in this research project.

The standard deviation, which is a measure of the heterogeneity of the analyzed wheat, barley and maize samples, was at a similar level for each method, regardless of the climatic and cultivation region from which the research material was collected. Based on the dispersion of these results, the level of crop uniformity can be estimated. The best moisture uniformity of wheat tested using the NIR method was obtained in cultivation region III, where the dispersion of the results was only S = 0.24%, for barley from region VI (S = 0.33%), and for maize from region IV (S = 3.37%) (Table 2–4). Similar relationships were also demonstrated for GAC/MA methods in these climatic and cultivation areas. It should be noted that the obtained grain moisture results were largely dependent on the climatic and growing conditions, but despite this, based on the research conducted, it was found that the NIR/GAC/MA research methods can be used interchangeably. The economic aspect is also important, as the cost of purchasing the NIR method is at least €30,000, the capacitive method is about €8.000 and the MA method is only about €700. From a business point of view, the analysis time is also important - the shortest was obtained for the capacitive GAC method and for the NIR method (of the order of a few minutes). For the MA method, the analysis time is at least several minutes. The seemingly simple NIR/GAC/MA methods, however, require some minimal knowledge of the operation of measuring devices and sample preparation methods. Combining knowledge from these two areas is necessary to obtain true results, which can be the basis for the quality assessment of grains, but also an indication for improving crops grown in specific climatic and cultivation areas.

In general, the lack of discrepancies in the grain moisture results as presented in the paper is not a disadvantage. It is objective evidence that the normative NIR and GAC methods were applied according to the requirements of the standards and that the validation of the MA method was carried out correctly. It is also a clear indication to other research processes that relatively cheaper methods (MA) can be used instead of very expensive methods (NIR).

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