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# SOFTWARE SUPPORTING DETERMINATION OF INITIAL MASS OF DRIED GRAIN KERNELS SAMPLE

*Summary*

*Research on the drying processes of grain kernels in a thin layer requires data on moisture content changes inside kernels in selected time intervals of these processes. Before experimental tests to determine these changes are preformed, it is essential to assume the initial mass of grain samples. Deliberate determination of its value, taking into account the uncertainty of measuring instruments in the determination of sample mass in selected time intervals and sample dry mater content, provides results with a possibly low uncertainty. Unfortunately, despite the fact that the method for determining the initial mass of samples is generally available, quite often its value is not assumed deliberately. Therefore, the objective of this study was to develop software that could help in the determination of the initial mass of grain kernel samples dried in a thin layer. The paper also includes example results obtained with the use of the developed software, used for its validation.*
***Key words**: initial sample mass, moisture content determination, grain drying, computer software*

# OPROGRAMOWANIE WSPOMAGAJĄCE OKREŚLANIE POCZĄTKOWEJ MASY PRÓBKI SUSZONEGO ZIARNA ZBÓŻ

*Streszczenie*

*Badanie procesów suszenia ziarna zbóż w cienkiej warstwie wymaga znajomości zmian zawartości wody w jego wnętrzu w kolejnych krokach czasowych tych procesów. Przed przystąpieniem do badań doświadczalnych dążących do poznania tych zmian niezbędne jest przyjęcie początkowej masy próbki suszonego ziarna. Świadome określenie jej wartości, z uwzględnieniem niepewność przyrządów pomiarowych służących do określania masy próbki w kolejnych krokach czasowych i masy suchej substancji w próbce, umożliwia otrzymanie wyników obarczonych możliwie niską niepewnością. Niestety pomimo tego, że metoda określania początkowej masy próbki suszonego materiału jest ogólnie dostępna, w badaniach dość często jej wartości nie przyjmuje się w pełni świadomie. Dlatego też celem pracy było opracowanie oprogramowania, które ułatwi określanie początkowej masy próbki ziarna zbóż suszonego w cienkiej warstwie. W pracy zawarto również przykłady wykorzystania wytworzonego oprogramowania, które zostały wykorzystane do jego walidacji.*
***Słowa kluczowe**: początkowa masa próbki, wyznaczanie zawartości wody, suszenie ziarna zbóż, oprogramowanie komputerowe*

## 1. Introduction

Research has been conducted both in Poland and worldwide on the construction of mathematical models describing drying processes of various products, including cereal grain [2, 4, 5, 8]. Among these models we may distinguish both empirical formulas which importance is limited basically only to the generalization of measurement results and theoretical models, aiming first of all at the identification of these processes. Most theoretical models describing cereal grain drying processes in commercial practice include grain drying models in a thin layer. It needs to be stressed that a thin grain layer is such a convection-dried layer which should be described using equations applied in modelling of single kernels subjected to the drying processes. In practice this concept refers not only to the grain layers of a single kernel thickness, but also to grain layers with a thickness greater than that of a single kernel, at the assumption that temperature and relative humidity of drying air remain in the same thermodynamic state at each point in the grain layer and at each time point of the drying process [5]. In studies of grain drying processes it is most frequently assumed that these processes take place only in the second drying period, referred to as the period of decreasing drying rate, thus the inner water exchange conditions have a decisive effect on their course [7].

Studies on cereal grain drying processes occurring in a thin layer require information on changes in moisture content inside kernels in the following time intervals of these processes. Kinetics of drying is determined on the basis of data on the mass of the sample in these steps $M(\tau)$ and dry substance mass in sample $M_s$, using the following dependence:

$$u(\tau) = \frac{M(\tau) - M_s}{M_s} \ [\mathrm{kg_{water}} \cdot \mathrm{kg_{d.m.}}^{-1}], \tag{1}$$

where:
$\tau$ – time,
u – moisture content (d.b.) of the sample,
M – mass of the sample,
$M_s$ – mass of dry substance in the sample.

Prior to the initiation of experimental studies concerning cereal grain drying in a thin layer it is necessary to assume the initial mass of a grain sample. A deliberate determination of its value, in view of the unreliability of measurement devices used to determine mass of the sample in successive time steps of the process and dry substance mass in the sample, may provide results burdened with a potentially low uncertainty [1]. Unfortunately, despite the fact that the method to determine the minimal initial mass of the sample is readily available, in studies connected with the determination of kinetics of cereal kernel drying processes relatively often its values are not adopted completely deliberately. Thus the aim of this study was to develop a software which would facilitate specification of the initial sample mass for cereal grain dried in a thin layer. Thanks to such a software individuals intending to conduct experimental studies connected with the determination of changes in moisture contents in dried cereal grain would be able to estimate this value in a simple manner.

## 2. A method to determine the initial sample mass

The relative error for the determination of moisture content in a sample is established using the exact differential method, taking into consideration uncertainty of the measurement for this sample in successive time steps $|\Delta M(\tau)|$ and uncertainty of the dry substance measurement in that sample $|\Delta M_s|$ [1]:

$$\delta u \leq \frac{100}{M(\tau) - M_s}\left[|\Delta M(\tau)| + \frac{M(\tau)}{M_s} \cdot |\Delta M_s|\right] [\%], \qquad (2)$$

where:
$\tau$ – time,
$\delta u$ – relative error of determination of moisture content,
M – mass of the sample,
$M_s$ – mass of dry substance in the sample,
$|\Delta M(\tau)|$ – uncertainty of measurements of sample mass,
$|\Delta M_s|$ – uncertainty of measurement of dry substance mass in the sample.

Prior to the onset of the experiment neither the mass of sample not the dry substance mass in the sample are known. However, after [1] when transforming these two values to the function of moisture content, w.b. *w* and the expected initial moisture content, w.b. $w_0$ dependence (2) may be presented in the following form:

$$\delta u \leq \frac{100 \cdot (100 - w)}{M_0 \cdot w(100 - w_0)}\left[|\Delta M(\tau)| + \frac{100}{100 - w} \cdot |\Delta M_s|\right] [\%], \qquad (3)$$

where:
$\tau$ – time,
$\delta u$ – relative error of determination of moisture content,
w – moisture content (w.b.) of the sample,
$w_0$ – initial moisture content (w.b.) of the sample,
$|\Delta M(\tau)|$ – uncertainty of measurements of sample mass,
$|\Delta M_s|$ – uncertainty of measurement of dry substance mass in the sample.

When analyzing dependence (3) it may be observed that uncertainty of measurements of changes in moisture content, d.b. in a dried sample depends on the initial sample mass $M_0$, its moisture content, w.b. and initial moisture content, w.b., as well as uncertainty of measuring devices. Assuming the value of the maximum relative error for the determination of moisture content, d.b. in sample $\delta_z$, such that $\delta u \leq \delta_z$, the initial sample mass may be estimated using dependence [1]:

$$M_0 > \frac{100 \cdot (100 - w)}{\delta_z \cdot w(100 - w_0)}\left[|\Delta M(\tau)| + \frac{100}{100 - w} \cdot |\Delta M_s|\right] [\mathrm{g}], \qquad (4)$$

where:
$\tau$ – time,
$M_0$ – initial mass of the sample,
$\delta_z$ – maximum relative error of determination of moisture content,
w – moisture content (w.b.) of the sample,
$w_0$ – initial moisture content (w.b.) of the sample,
$|\Delta M(\tau)|$ – uncertainty of measurements of sample mass,
$|\Delta M_s|$ – uncertainty of measurement of dry substance mass in the sample.

Dependence (4) constituted the basis for the development of the software discussed in this study.

## 3. Description of the developed software

The PMPZ 2011 software used to determine the initial sample mass for cereal grain dried in a thin layer was developed within the framework of an Engineer's thesis by Michał Maciejewski, prepared at the Institute of Biosystem Engineering, the Poznan University of Life Sciences [3]. This application was produced in accordance with the standards of software engineering [6]. An integral stage in the construction of this software was to determine the functional and non-functional requirements it has to meet, as well as to develop diagrams: use case, class, communication and sequence using the UML notation. The implementation stage for the PMPZ 2011 to the form of a window application, operating under the control of Microsoft Windows operating systems, was performed in the C# programming language using the Microsoft Visual Studio 2010 programming environment. In the produced software the ZedGraph library was used [9] which is a tool facilitating generation of graphs.

Functional requirements for the application were met taking into consideration the following functions:

- entering data for calculations,
- calculation of the minimal initial cereal grain sample mass based on the entered data,
- generation of a graph for the relationship between the minimal initial grain sample mass and its moisture content, w.b.,
- printing of the generated graph,
- clearing of the graph,
- deletion of entered data,
- closure of the application.

The main window of the PMPZ 2011 program is presented in Fig. 1.

The application is relatively user-friendly. On the right of the main window there are 5 text boxes, in which data required for the calculation of the minimal initial sample mass need to be entered, i.e.:

- expected initial moisture content, w.b. of the dried material,
- expected final moisture content, w.b. of the dried material,
- admissible relative error for the determination of sample moisture content, d.b.
- uncertainty of the balance used to measure sample mass in successive time steps of the drying process,
- uncertainty of the balance used to measure dry substance mass in the sample after the completion of the drying process.

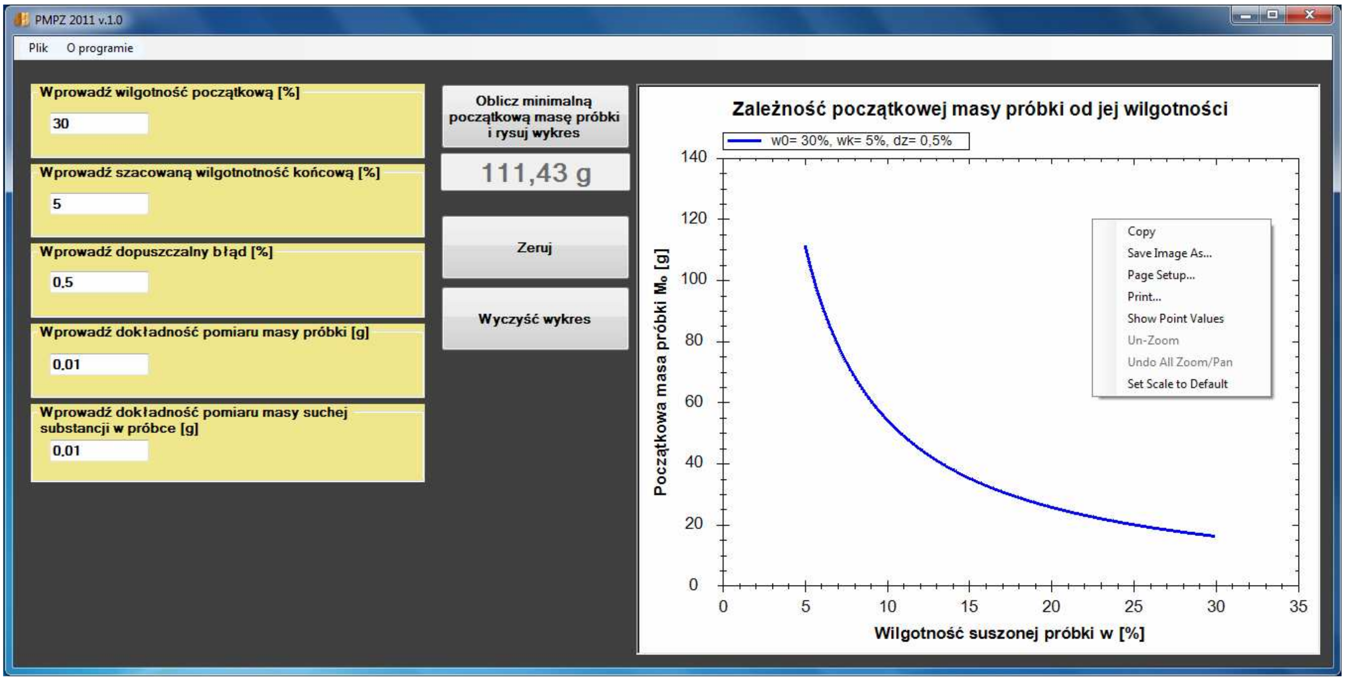


Fig. 1. The main window of PMPZ 2011 software (*Source*: the authors' study)
*Rys. 1. Okno główne oprogramowania PMPZ 2011 (Źródło: opracowanie własne)*

Clicking the button „Oblicz minimalną początkową masę próbki i rysuj wykres" (Calculate the initial sample mass and plot the graph) results in:

- collection of data entered in the form by the user,
- substitution of entered data in the function used to determine the minimal initial sample mass,
- calculation and displaying of the minimal initial sample mass in the form,
- generation of a graph for the dependence between the minimal initial sample mass and sample moisture content, w.b. in the form.

The dependence between the minimal initial grain sample mass and its moisture content, w.b. is determined and presented in the form of a graph in the range from the adopted initial to the adopted final moisture content, w.b. of the sample. Using the context menu available after clicking the graph with the right mouse button the following operations are available: e.g. copying of the graph to the clipboard, saving the graph in a file using several popular raster graphics formats (including PNG, GIF, JPEG, TIFF and BMP), printing of the graph and changing the scale of the graph display. Additional buttons available from the level of the main window of this application, i.e. "Zeruj" (Reset) and "Wyczyść wykres" (Clear the graph) are responsible for deleting of data entered in the form text boxes and clearing of the graph.

## 4. Examples of the software applications

The operation of the developed software was tested using available combinations of the following input data:

- expected initial moisture content, w.b. of the material $w_0$: 20 and 30%,
- expected final moisture content, w.b. of the material $w_k$: 10 and 14%,
- admissible relative error for the determination of moisture content, d.b. in the sample $\delta_z$: 0.5 and 1%,
- uncertainty of sample mass measurement $|\Delta M(\tau)|$: 0.01 and 0.05 g,
- uncertainty of sample dry substance mass measurement $|\Delta Ms|$: 0.01 and 0.05 g.

Results of the minimal initial grain sample mass are given in Tables 1-4. These tables refer to the following moisture content, w.b. ranges in dried kernels: 10-20%, 14-20%, 10-30% and 14-30%.

Table 1. Minimal initial mass of grain sample dried in a thin layer for its initial moisture content, w.b. of 20% and final moisture content, w.b. of 10% (*Source*: the authors' study)
*Tab. 1. Minimalna początkowa masa próbki ziarna suszonego w cienkiej warstwie dla jego wilgotności początkowej 20% i końcowej 10% (Źródło: opracowanie własne)*

| Admissible relative error for the determination of moisture content, d.b. $\delta_z$ [%] | Uncertainty of sample mass measurement $|\Delta M|$ [g] | Uncertainty of sample dry substance mass measurement $|\Delta M_s|$ [g] | Minimal initial sample mass $M_0$ [g] |
|---|---|---|---|
| 0.5 | 0.01 | 0.01 | 47.50 |
| 0.5 | 0.01 | 0.05 | 147.50 |
| 0.5 | 0.05 | 0.01 | 137.50 |
| 0.5 | 0.05 | 0.05 | 237.50 |
| 1 | 0.01 | 0.01 | 23.75 |
| 1 | 0.01 | 0.05 | 73.75 |
| 1 | 0.05 | 0.01 | 68.75 |
| 1 | 0.05 | 0.05 | 118.75 |

Table 2. Minimal initial mass of grain sample dried in a thin layer for its initial moisture content, w.b. of 20% and final moisture content, w.b. of 14% (*Source*: the authors' study)
*Tab. 2. Minimalna początkowa masa próbki ziarna suszonego w cienkiej warstwie dla jego wilgotności początkowej 20% i końcowej 14% (Źródło: opracowanie własne)*

| Admissible relative error for the determination of moisture content, d.b. $\delta_z$ [%] | Uncertainty of sample mass measurement $\|\Delta M\|$ [g] | Uncertainty of sample dry substance mass measurement $\|\Delta M_s\|$ [g] | Minimal initial sample mass $M_0$ [g] |
|---|---|---|---|
| 0.5 | 0.01 | 0.01 | 33.21 |
| 0.5 | 0.01 | 0.05 | 104.64 |
| 0.5 | 0.05 | 0.01 | 94.64 |
| 0.5 | 0.05 | 0.05 | 166.07 |
| 1 | 0.01 | 0.01 | 16.61 |
| 1 | 0.01 | 0.05 | 52.32 |
| 1 | 0.05 | 0.01 | 47.32 |
| 1 | 0.05 | 0.05 | 83.04 |

Table 3. Minimal initial mass of grain sample dried in a thin layer for its initial moisture content, w.b. of 30% and final moisture content, w.b. of 10% (*Source*: the authors' study)
*Tab. 3. Minimalna początkowa masa próbki ziarna suszonego w cienkiej warstwie dla jego wilgotności początkowej 30% i końcowej 10% (Źródło: opracowanie własne)*

| Admissible relative error for the determination of moisture content, d.b. $\delta_z$ [%] | Uncertainty of sample mass measurement $\|\Delta M\|$ [g] | Uncertainty of sample dry substance mass measurement $\|\Delta M_s\|$ [g] | Minimal initial sample mass $M_0$ [g] |
|---|---|---|---|
| 0.5 | 0.01 | 0.01 | 54.29 |
| 0.5 | 0.01 | 0.05 | 168.57 |
| 0.5 | 0.05 | 0.01 | 157.14 |
| 0.5 | 0.05 | 0.05 | 271.43 |
| 1 | 0.01 | 0.01 | 27.14 |
| 1 | 0.01 | 0.05 | 84.29 |
| 1 | 0.05 | 0.01 | 78.57 |
| 1 | 0.05 | 0.05 | 135.71 |

Table 4. Minimal initial mass of grain sample dried in a thin layer for its initial moisture content, w.b. of 30% and final moisture content, w.b. of 14% (*Source*: the authors' study)
*Tab. 4. Minimalna początkowa masa próbki ziarna suszonego w cienkiej warstwie dla jego wilgotności początkowej 30% i końcowej 14% (Źródło: opracowanie własne)*

| Admissible relative error for the determination of moisture content, d.b. $\delta_z$ [%] | Uncertainty of sample mass measurement $\|\Delta M\|$ [g] | Uncertainty of sample dry substance mass measurement $\|\Delta M_s\|$ [g] | Minimal initial sample mass $M_0$ [g] |
|---|---|---|---|
| 0.5 | 0.01 | 0.01 | 37.96 |
| 0.5 | 0.01 | 0.05 | 119.59 |
| 0.5 | 0.05 | 0.01 | 108.16 |
| 0.5 | 0.05 | 0.05 | 189.80 |
| 1 | 0.01 | 0.01 | 18.98 |
| 1 | 0.01 | 0.05 | 59.80 |
| 1 | 0.05 | 0.01 | 54.08 |
| 1 | 0.05 | 0.05 | 94.90 |

Figure 2 presents a screen shot from the application presenting an example dependence between the minimal sample mass and its moisture content, w.b. ranging from 30 to 10%, taking into account an admissible relative error for the determination of moisture content, d.b. of 0.5% and uncertainty of measurements of sample mass and sample dry substance mass at 0.05 g. The next example dependence for the moisture content, w.b. of the material decreasing from 20 to 14%, at the assumption of the relative error of 1% and uncertainty of measurements for sample mass and sample dry substance mass of 0.01 g, is given in Fig. 3.

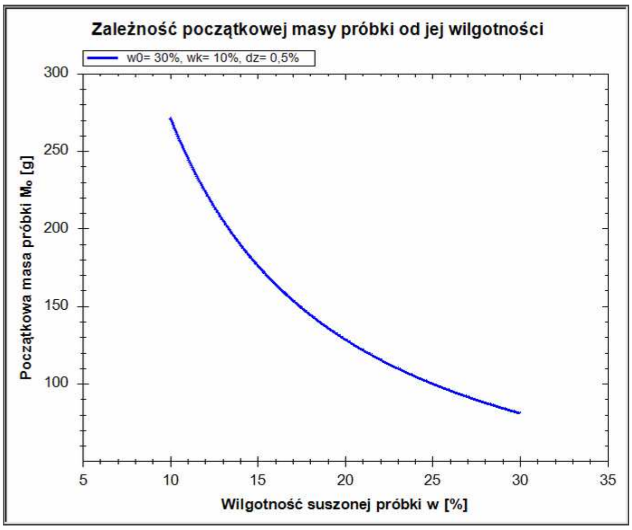


Fig. 2. The relation between the initial mass of sample and its moisture content, w.b. ($w_0$=30%, $w_k$=10%, $\delta_z$=0.5%, $|\Delta M|$=0.05 g, $|\Delta M_s|$=0.05 g) (*Source*: the authors' study)
*Rys. 2. Zależność początkowej masy próbki od jej wilgotności ($w_0$=30%, $w_k$=10%, $\delta_z$=0,5%, $|\Delta M|$=0,05 g, $|\Delta M_s|$=0,05 g) (Źródło: opracowanie własne)*

Results of the minimal initial cereal grain mass as well as graphs for the dependence between its value and grain moisture content, w.b. were used in the validation of the developed software. After validation it was stated that for the correct input data the application provides correct results and meets all the imposed requirements.

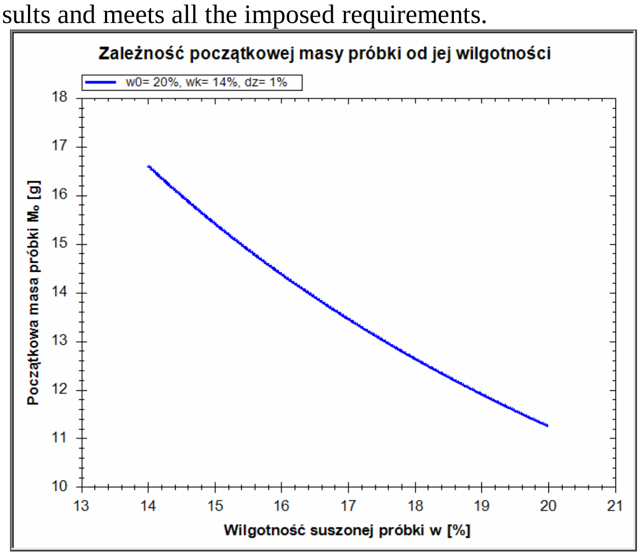


Fig. 3. The relation between the initial mass of sample and its moisture content, w.b. ($w_0$=20%, $w_k$=14%, $\delta_z$=1%, $|\Delta M|$=0.01 g, $|\Delta M_s|$=0.01 g) (*Source*: the authors' study)
*Rys. 3. Zależność początkowej masy próbki od jej wilgotności ($w_0$=20%, $w_k$=14%, $\delta_z$=1%, $|\Delta M|$=0,01 g, $|\Delta M_s|$=0,01 g) (Źródło: opracowanie własne)*

## 5. Conclusions

Despite the fact that the software was developed to determine the initial sample mass for experimental studies connected with the determination of changes in moisture content in cereal grain dried in a thin layer, it may be used to determine this value for any dried solid. In view of the fact that the developed software is a window application operating under the control of Microsoft Windows operating systems, its availability is currently considerably limited. However, in the nearest future it is planned to produce the next version of the application implemented to the form of an Internet system which will be an open-access source for all interested users.

In relation to the contents presented in this study the following conclusions may be formulated:
1. The produced software makes it possible to determine the initial sample mass for cereal grain dried in a thin layer.
2. Validation of the produced software showed that it meets all the imposed requirements.

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