Mass transfer of wholegrain ready mixture with elderberry

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Abstract. In recent years, an increasing number of studies have focused on searching of alternative versions of using waste products rich in natural nutrients form different productions. The received results of the physico-chemical analysis and the sorption characteristics of wholegrain ready flour mixture with added quantity of a waste product – elderberry after alcohol fermentation in juice production, are described in the current paper. The nutritional profile of the flour mixture shows that the product is well balanced with significant quantity of carbohydrates 62.32g, dietary fibre 13.65g, low content of fats 3.97g. The total energy value of the product is relatively high which makes it appropriate for consumption as a part of a balanced diet. The conducted mass transferring experiment with ready flour mixture is implemented for three temperatures (10°C, 25°C and 40°C) and eight relative air humidities in the range from 11% to 87%. The received equilibrium moistures content are with confirmative character for food products, with increase of temperature in constant air humidity the values of the equilibrium moisture content lower. The suggested modified model appropriate for isotherms description in conformity with the eligibility criteria is Halsey. The values of the monolayer moisture content received by linearization of the BET model show direct dependence with the temperature for the experiment conditions. In increase of the temperature from 10°C to 40°C the monolayer moisture lowers with c 2.6 % dry mass for the process of absorption and 2.2 % dry mass for desorption.

1 Introduction

The consumption of wholegrain food products dates back thousands of years; however, some contemporary nutritionists claim that cereals are unhealthy. Studies have shown that refined grains are associated with health problems such as obesity and inflammation. In contrast, wholegrain products are rich in essential nutrients that provide numerous health benefits.

The wholegrain food products contain several grams of protein per portion, fibre, vitamins. Additionally, they are especially rich in vitamins from the B group, including niacin, thiamine and folate, minerals as zinc, magnesium, iron, manganese. They are also abundant in various plant compounds, including polyphenols, stanols, and sterols [1], which play an important role in the prevention of various diseases. Many of these compounds act as antioxidants, such as phytic acid, ferulic acid, lignans, and sulphur-containing compounds [2]. The quantity of these nutrients may vary depending on the type of grain used.

Wholegrain food products consumption may considerably lower the risk of heart diseases which are major reason for death in global scale. Studies show that the consumption of three portions wholegrain food products daily, 30 grams each, may lower the risk of heart diseases with 22% [3]. A 10-year research including 17 424 adults reveals that those who consume the largest share wholegrain products towards their total consumption of carbohydrates, have 47% lower risk of heart diseases [4].

The consumption of wholegrain food products instead of refined products may reduce the risk of developing type 2 diabetes. A review of 16 studies concludes that replacing refined grains with wholegrains in amounts of at least two servings per day may decrease the likelihood of diabetes development [5]. This effect is attributed to the high fibre content of these foods, which supports weight regulation and helps prevent obesity, a major risk factor for diabetes [6].

Wholegrain food products with high fibre content provide multiple benefits for digestive system health. One of the primary functions of dietary fibre is to increase faecal bulk and reduce the risk of constipation. Furthermore, certain types of fibre present in wholegrain foods may act as prebiotics, promoting the growth of beneficial bacteria in the intestinal microbiota [7].

Wholegrain food products inclusion in everyday dishes is an easy way to improve health and longevity.

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Considering the increasing interest of the food industry and households in the utilization of waste products from elderberry juice production, as well as the limited scientific information available according to the literature review, the aim of the present study was defined. Specifically, the study focused on investigating the sorption characteristics of a newly developed wholegrain ready mixture containing a waste product of elderberry juice production after alcohol fermentation.

2 Materials and methods

2.1 Raw Materials

The products used in the research are:

- Bulgarian herbaceous elderberry "*Sambucus ebulus*" after alcohol fermentation – a waste product in production of tincture. The berries are delivered from the area of Zlatosel village, Brezovo municipality, southern Bulgaria;
- Rye flour type 1750 – "Mlivo 1937" Ltd. Company, Plovdiv;
- Wholegrain wheat flour type 1850 - "Mlivo 1937" Ltd. Company, Plovdiv;
- Carob flour – "Bioworld" Ltd., Sofia. Product of biological agriculture;
- Raisins – Packaged from "2A" company, Plovdiv;
- Water – spring DEVIN.

2.2 Methods

- **Nutritional profile:**

\- Moisture [%] – by express method by drying of 5g flour for 24 h in 105 ºC according to AOAC [8].
\- Fibre - BSS 11374:1986 [9];
\- Carbohydrate - BSS 7169:1989 [10];
\- Protein – Direct Kjeldahl method analysis (determination of nitrogen content/ nitrogen determination method) – Regulation (EC) №152/2009 [11];
\- Fat content, (%) – Soxhlet method via solvent extraction with petroleum ether. BSS 6997:1984 [12].

- **Sorption characteristics:**

A static gravimetric method is used, recommended by Project COST 90 [13] and updated by Bell & Labuza, 2000 [14]. The modified three-parametric models of Oswin, Chung-Pfost, Halsey and Henderson [15] are used for description of the sorption isotherms. The linearized model of Brunayer-Emmett-Teller (BET) [16] is used for calculation of the monolayer moisture content.
The full description of the used method and the subsequent modelling of the sorption characteristics is described in details and presented by Durakova et al., 2020 [2].

All conducted experiments are in triple repeatability.

3 Results and discussion

A ready-made flour mixture intended for the production of a final product—bread designed to support proper metabolic processes in the human body—was developed. The analysis of the mixture indicates a balanced macronutrient profile, making it suitable for application in the production of wholegrain bread and confectionery products. The incorporation of waste materials obtained from elderberry pressing is not only economically justified but also aligns with contemporary requirements for circular bioeconomic and sustainability. The average values of the chemical composition of the flour mixture (rye flour type 1750, wholegrain wheat flour type 1850, carob flour, raisins, water, and elderberry pressing) demonstrate a well-balanced nutritional profile, as presented in Table 1.

Table 1. Nutritional profile and energy value of 100 g product

Indicators	Values
Carbohydrates, g	62.32±0.25
Dietary fibre, g	13.65±0.49
Proteins, g	11.99±0.30
Fats, g	3.97±0.04
Energy value, kcal	360.25±2.79

The nutritional profile of the flour mixture indicates a well-balanced product with a considerable carbohydrate content of 62.32 g and dietary fibre content of 13.65 g. The low-fat content (3.97 g) suggests that the mixture is relatively low in calories, while still providing healthy fats that are essential for vitamin absorption and normal cellular function. The dietary fibre content of 13.65 g represents a significant amount, contributing to the maintenance of normal digestive system function and the regulation of cholesterol levels. In addition, dietary fibre may promote prolonged satiety. The total energy value of the product is relatively high, making it suitable for consumption as part of a balanced diet. This energy value reflects the carbohydrate and fat content, which constitute the primary sources of calories. The combination of rye flour, wholegrain wheat flour, carob flour, raisins, water, and elderberry pressing renders the mixture appropriate for inclusion in health-oriented functional food products, contributing to the maintenance of normal energy levels and digestive health. The obtained analytical results are consistent with data reported in the literature, which describe similar nutritional profiles for products based on wholegrain flours or dried fruits [18–19].

The sorption characteristics of the ready flour mixture with added elderberry were determined at temperatures of 10°C, 25°C, and 40°C, within a water activity range from 11% to 87%. The initial moisture content of the examined product was 11.58% dry mass. After ten days of hydration over ΔH_2O, the moisture content reached 17.94%, while dehydration over P_2O_5 resulted in a moisture content of 6.65% d. m.

The obtained equilibrium moisture content values for adsorption and desorption processes are presented in Figures 1 and 2.

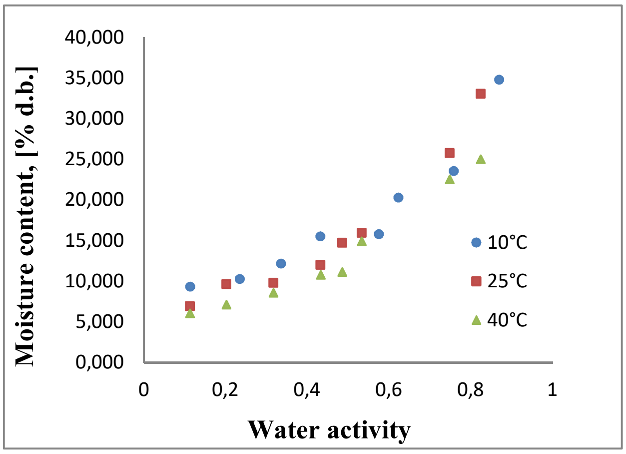

Figure 1. Equilibrium moisture content for the process adsorption

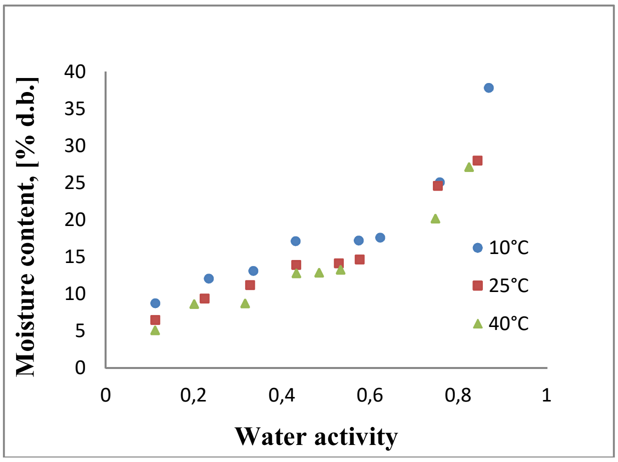

Figure 2. Equilibrium moisture content for the process desorption

The figures illustrate the typical behaviour of equilibrium moisture content in food products, specifically that an increase in temperature at constant air humidity leads to a decrease in moisture content values [2, 14–15].

The sorption isotherms for both adsorption and desorption clearly exhibit an *S*-shaped profile, classifying them as Type II according to Brunauer's classification (Brunauer et al., 1940) [2, 15, 17].

The coefficients of the modified three-parameter models applied in the analysis (Table 2) were calculated using the least squares method with non-linear regression software *Statistica*. The average relative error (P, %) and the standard error (SEM) were determined, and the distribution of residuals for both processes is presented in Figures 2 and 3.

Table. 2. Coefficients of the models (A, B, C), average relative error (P, %) and standard deviation (SEM) for adsorption.

Model	A	B	C	P	SEM
Oswin	16.77	-0.087	0.43	9.27	1.49
Halsey	**4.45**	**-0.015**	**1.69**	**7.59**	**1.84**
Henderson	0.000184	1.967	1.88	20.7	4.66
Chung-Pfost	329.79	0.116	59.61	12.82	2.40

Table. 3. Coefficients of the models (A, B, C), average relative error (P, %) and standard deviation (SEM) for desorption.

Model	A	B	C	P	SEM
Oswin	17.57	-0.105	0.41	9.13	1.63
Halsey	**4.83**	**-0.015**	**1.80**	**9.26**	**1.67**
Henderson	0.000133	3.149	1.86	21.1	5.69
Chung-Pfost	-	-	-	-	-

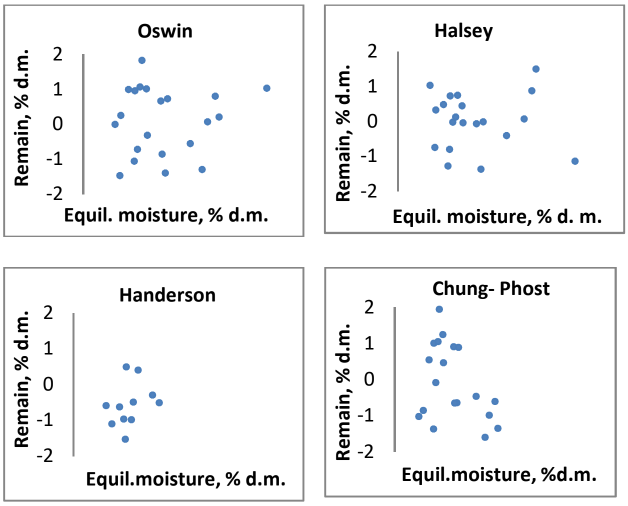

Figure 3. Distribution of residuals for the process adsorption

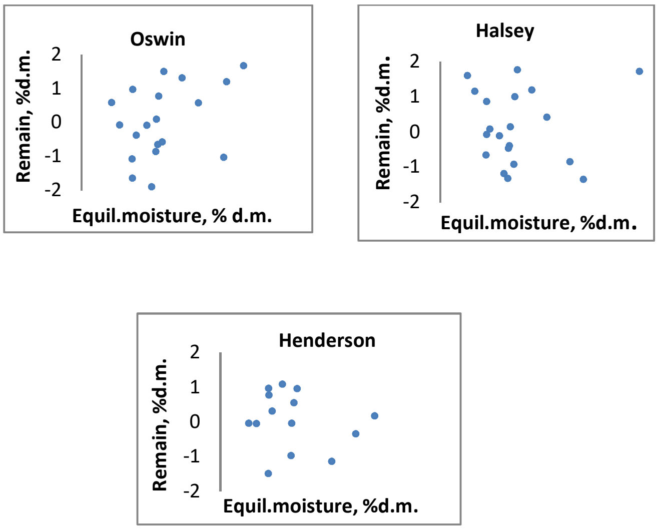

Figure 4. Distribution of residuals for the process desorption

Statistical analysis of the results indicated that the lowest values of average relative error (P, %) and standard error (SEM) were obtained using the modified Halsey model. The residuals distribution for this model exhibits a random pattern, which, according to the criteria for model evaluation and validation, provides justification for recommending the three-parameter Halsey model for describing the sorption characteristics of the ready flour mixture [2, 13–14].

The monolayer moisture content of the examined product was determined by fitting the BET model in linear form to experimental data for water activity values below 0.5. The corresponding adsorption and desorption data are presented in Figures 5 and 6. The monolayer moisture values, shown in Table 4, were calculated from the coefficients of the linear equations.

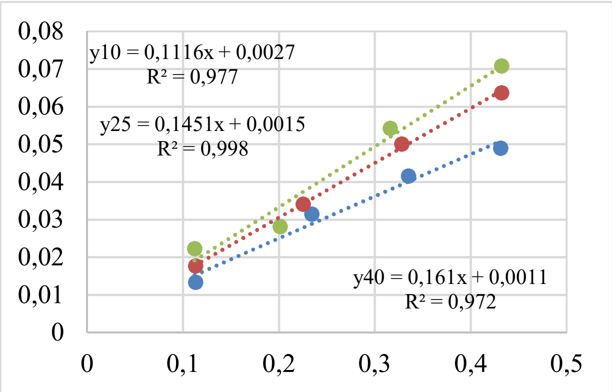

Figure 5. Linearization of the BET model for different temperatures at adsorption

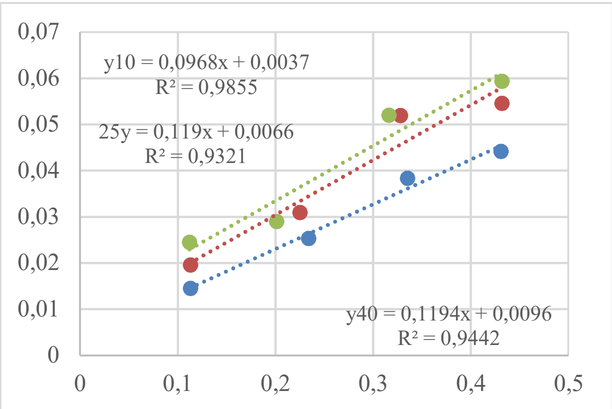

Figure 6. Linearization of the BET model for different temperatures at desorption

Table. 4. BET monolayer moisture, % d.m. at different temperatures *t*.

t (°C)	Adsorption	Desorption
10	8.75	9.95
25	6.82	7.96
40	6.17	7.75

The obtained monolayer moisture values indicate a dependency between moisture content and temperature for the examined product [2, 15–17]. In both adsorption and desorption processes, the monolayer moisture content decreases with increasing temperature. For adsorption, the decrease from 10°C to 25°C was 1.93% d.m., and from 25°C to 40°C it was 0.65% d.m., while for desorption the corresponding decreases were 1.99% d.m. and 0.21% d.m., respectively. Overall, within the temperature range of 10°C to 40°C, the total decrease was 2.65% d.m. for adsorption and 2.20% d.m. for desorption.

4. Conclusions

The nutritional profile (proteins, fats, carbohydrates, dietary fibre and energy value) of composed ready flour mixture with added waste product elderberry is analysed. The chemical composition shows that the received flour mixture is stable and well balanced.

The received equilibrium moistures content are with affirmative character for the food products; with the increase of the temperature and the constant air humidity, the equilibrium moisture content values decrease.

The modified model, appropriate for isotherms' description and meeting the eligibility criteria for the ready flour mixture, is Halsey.

The monolayer moisture values received through BET model linearization indicate direct correlation with the temperature for the conditions of the experiment.

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