Chemical Composition and Rheological Parametrs of *Helianthus Tuberosus* Flour Used as a Sources of Bioactive Compounds in Bakery

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The main aim of this study was to establish the optimum dose of Jerusalem artichoke (Helianthus tuberosus L.) flour to be used as a functional ingredient in the bakery products industry, from both a nutritional and technological point of view. H. tuberosus has an important functional potential given by its high content of inulin, minerals, amino acids, and organic silicon. In this work, H. tuberosus flour was used for the enrichment of wheat flour with functional biocompounds. The experiments evaluated the functional potential of wheat flour enriched with H. tuberosus flour, in different proportions, by examining the chemical composition and rheological behaviour of the doughs. It was found that incorporation up to a 5% into the formulation of wheat flour yielded an acceptable product in terms of rheological parameters, with improved nutritional and functional properties.

Keywords: bakery functional ingredient, inulin, mineral

Known for over 2000 years, Jerusalem artichoke (*Helianthus tuberosus* L.) from the Asteraceae family is a perennial plant found in the Northeast of USA. It is cultivated in temperate areas for its edible tuber. As a source of inulin, which has aperient, cholagogue, diuretic, spermatogenic, stomachic and tonic effects, its tuber has been used as a traditional remedy in the treatment of diabetes and rheumatism [1].

More recently, research done by multiple teams has proven that the chemical composition of *H. tuberosus* has a positive influence on gastrointestinal system mechanisms, as the plant contains a high concentration of minerals [2-4] and inulin [5, 7, 8].

Literature surveys reveal a massive consumer interest in bakery products enriched with functional ingredients; thus, technological developments have been made towards developing more products of this kind [9]. Many research studies have been carried out, with the purpose to improve the nutritional values and functional properties of wheat flour that involved the addition of numerous other ingredients, such as dietary fibre from coconut flour [10], mango peels as an antioxidant source [9, 11], soy protein [12], apple pomace [13], olives, onion, garlic [14], potato peel [15] and guar gum [16]. In addition, Bajiæ et al. [17] have used plant extracts (rosemary, thyme, sage) in the production of bakery products. Inulin mixed with water creates a gel network, which gives a smooth and creamy texture [18-19]. The aim of this study shows how *H. tuberosus* also can be utilized to increase the dietary fibre and mineral content of wheat flour.

Experimental part

Materials and methods

Jerusalem artichoke (*Helianthus tuberosus* L.) tuber flour was supplied by SC Hofigal Export Import SA, (Bucharest, Romania) and obtained by finely grinding the tubers. The wheat flour used in the study was type 550 (0.55% dry matter (DM) ash content) and was provided by Titan SA (Bucharest, Romania).

Preparation of flour mixtures. As shown in table 1, four samples of mixtures of wheat flour (type 550) with different proportions of *H. tuberosus* tuber flour were prepared by mixing in the following ratios: 95:5, 90:10, 85:15 and 80:20 (w/w). P1 is 100% wheat flour and P6 is 100% *H. tuberosus* tuber flour.

Chemical analysis

Moisture was determined at 103°C (±2°C) using test samples weighing 2 g, until constant weight was achieved between measurements, as described in the ICC Standard No. 110/1. The ash content was determined by incineration at 525 ± 25°C (ICC No. 104/1). Total fat was determined by extracting 10 g of sample with petroleum ether 40-65°C, using a semiautomatic Soxhlet Foss Extraction System 2055 (Foss, Sweden). Total nitrogen (N) and crude protein content (N 6.50, conversion factor) was estimated using the Macro Kjeldahl method (Kjeltec System, FOSS, Sweden). Total fibre was measured using the enzymatic gravimetric method, Mes-Tris buffer, AOAC (1995) method 991.43. The determination was performed using the Fibertec 1023 system (FOSS Sweden). Each sample was analysed in triplicate.

Table 1
TYPES OF FLOURS USED IN THE EXPERIMENTS

P1	100% wheat flour (type 550)
P2	95% wheat flour (type 550)+5% *H. tuberosus* tuber flour
P3	90% wheat flour (type 550)+10% *H. tuberosus* tuber flour
P4	85% wheat flour (type 550)+15% *H. tuberosus* tuber flour
P5	80% wheat flour (type 550)+20% *H. tuberosus* tuber flour
P6	100% *H. tuberosus* tuber flour

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All the authors had equal contribution at this original article.

Inulin analysis

Inulin was determined according to the *Determination of inulin in dough products* method, Petkovaet al. [20]: the inulin extraction from the samples was carried out in an Ultrawave ultrasonic bath operating at a 60 Hz ultrasonic frequency and at 240 V. Then the samples were centrifuged in an Eppendorf 5804 R centrifuge. The spectrophotometric determination of fructans was carried out by the resorcinol assay. The absorbance of pink colored compound was read at 480 nm against distilled water.

The concentration of inulin in the sample extracts was calculated using the calibration curve of fructose [20-21]. Measurements were performed using a Jasco V 550 UV-Vis spectrophotometer.

The content of inulin was calculated by the method described in [20], using the formula:

$Y = 0.1174 X + 0.0087$; where: Y is absorbance at 480 nm; X – concentration of fructose, $\mu g\ mL^{-1}$.

Mineral analysis

The mineral contents were determined using the plasma-mass spectrometer ICP-MS (Perkin Elmer NexION 300Q). Total ash was determined by incineration of the samples at 550°C, in an oven. Analysis was performed using an external standard (Merck, multi element standard solution) and all calibration curves were obtained for six different concentrations. The total mineral content was measured using their most abundant isotopes. The dried samples were digested in a mixture of concentrated HCl. All measurements were made in triplicate.

Testing of rheological properties of doughs

The rheological behaviour of doughs was analysed using the predefined *Chopin* + protocol on Mixolab (www.chopin.fr), a piece of equipment created by CHOPIN Technologies, which uses the international standard ICC-Standard Method No. 173 protocol for a complete characterization of flours.

The procedure parameters used for the analysis with Mixolab are as follows: tank temperature 30°C, mixing speed 80 min^{-1}, heating rate 2°Cmin^{-1}, total analysis time 45 min.

The Mixolab curves are characterised by their torque in five defined points (*C1-C5,* N•m), as described in table 2, their temperatures and corresponding processing time. Mixolab tests the correlation between the parameters in table 3 during the mixing and heating of the dough [22].

Dough preparation and baking procedure

The bread formula is made from wheat flour, dried yeast (3.0 g), sodium chloride (1.5 g), *H. tuberosus* tuber flour, and water according to the Mixolab water absorption. Samples were coded according to table 1.

The mixtures of flours were sieved twice (sieve Nos. 70 and 212 mm). All ingredients were added into a mixer (Diosna, Germany). The program consisted of a kneading step of 10 min, then resting for 5 min prior to rounding and fermentation for 30 min at 28-30°C. Two dough pieces of 600 g were formed by re-shaping, placed in tins and then fermented at 30°C, RH 90%, 60 min. The fermented samples were baked at 200 ± 5°C in a baking oven (Mondial Forni-Verona). After baking, the bread was cooled down at room temperature for 2 h before measurements.

Specific volume measurement

Data is reported as the mean of three measurements, each loaf was weighed and its volume was determined by the rapeseed displacement method (AACC, 2000).

Porosity measurement

Porosity was determined by measuring the total volume of the holes in a known volume of crumb while mass and density are known. Porosity is expressed in % volume.

Elasticity was measured by applying a pressing force on a piece of bread crumb to bring it to half of its initial height and then removing the pressing force, and measuring the height recovery of the test sample one minute after removal of the load. Crumb elasticity is the ratio between the height expressed in % by pressing and return, and the initial height of the bread crumb.

Determination of sensory characteristics

The bread score is determined based on the quantification of a set of sensory characteristics, reported

Table 2

THE PARAMETERS USED TO EVALUATE MIXOLAB CURVES

Point	Significance	Associated parameters	
C1	Used to calculate water absorption	T°C 1 and T1	Dough temperature and the time required for different types of torque to appear
C2	Measures protein weakening as a function of mechanical work and temperature	T°C 2 and T2	
C3	Measures starch gelatinization	T°C 3 and T3	
C4	Measures the stability of the hot-formed gel	T°C 4 and T4	
C5	Starch retrogradation during the cooling period	T°C 5 and T5	

Table 3

MIXOLAB PARAMETERS

Parameter	Calculation method	Significance
Water absorption (%)	Quantity of water required to obtain C1 = 1.1 Nm +/– 0.05	Quantity of water the flour can absorb to achieve a given consistency during the constant temperature phase
Time for C1 (min)	Time required to obtain C1	Dough formation time: the stronger the flour, the longer it takes
Stability (min)	Time during which torque is >C1 – 11% (constant T° phase)	Dough resistance to kneading: The longer it takes the "stronger" the dough
Amplitude (N•m)	Curve width at C1	Dough elasticity: the higher the value, the greater the flour elasticity

to a standard volume of 400 cm^3100g^{-1} and 85% porosity, validated by Institute for Food Bioresources, Bucharest.

Moisture content measurement

Moisture content was determined by drying the bread crumb at 103°C (±2°C) to constant weight. For determination, approximately 5 g of crumb was taken from central slice of the loaf. Data are reported as the mean of three measurements, each one performed on a freshly made loaf. In table 4, is presented a summary of organoleptic evaluation scores.

Acidity measurement

Acidity, expressed in degrees (SR 91/2007), was determined by titration of an aqueous extract of bread with 0.1 N NaOH solution, in the presence of phenolphthalein as indicator.

Table 4

ORGANOLEPTIC EVALUATION SCORES

Indicator	Scores
Volume	24
Marginal crack height	7
Crust colour	7
Crumb appearance	10
Porosity	20
Elasticity	20
Aroma	12
Total	100

Statistical analysis

All analyses were performed in triplicate and the mean values with the standard deviations were reported. Microsoft Excel 2007 was employed for statistical analysis of the data with the level of significance set at 95%. Analysis of variance (ANOVA) followed by Tukey's test was used to assess statistical differences between samples. Differences were considered significant for a value of $P < 0.05$.

Results and discussions

Chemical analysis of flour mixtures. H. tuberosus tuber flour was chemically analysed to determine its contents of: proteins, ash, lipids and dietary fibre (soluble and insoluble) (table 5). These data confirm that *H. tuberosus* tuber flour is a good source of nutrients, especially inulin, which is the major component (63.01% DM) of total fibres (79.46% DM).

H. tuberosus tuber flour (P6) presents a high mineral content, being particularly rich in potassium (1.3%), calcium (0.29%), and magnesium (0.6%) (table 6). It can be noticed that compared to the low mineral content of wheat flour (P1), mixtures of wheat flour and *H. tuberosus* tuber flour have higher contents of minerals as the percentage of the latter component in the flour mixture increases.

Table 5

COMPONENTS OF WHEAT FLOUR, TUBER FLOUR AND THEIR MIXTURES

Composition % dry matter (DM)	P1	P2	P3	P4	P5	P6
Protein content	13.66±0.24	13.48±0.26	13.31±0.25	13.15±0.20	13.00±0.21	10.45±0.21
Ash content	0.55±0.01	0.79±0.02	1.03±0.03	1.29±0.04	1.54±0.05	5.6±0.10
Lipids content	1.11±0.06	1.06±0.06	1.05±0.08	1.03±0.07	1.01±0.07	0.75±0.06
Total sugar content	2.00±0.05	2.03±0.06	2.12±0.06	2.21±0.06	2.30±0.05	3.62±0.09
Total fibre content	1.8±0.13	5.6±0.40	13.35±0.83	16.01±0.77	17.02±0.88	79.46±1.19
Inulin content	0	3.12±0.27	6.15±0.45	9.40±0.30	12.35±0.63	63.01±1.02

Explanations of types of flours in table 1

Table 6

MINERAL CONTENTS OF WHEAT FLOUR, TUBER FLOUR AND THEIR MIXTURES

Mineral content,mg100 g^{-1}	P1	P2	P3	P4	P5	P6
Ca	43.81±0.68	49.92±0.99	56.08±1.02	62.22±1.01	68.36±1.05	166.77±0.95
Mg	47.70±1.05	50.07±1.11	52.30±1.15	54.51±1.15	56.70±1.11	92.15±1.34
Na	30.60±0.29	31.35±0.29	32.11±0.30	32.89±0.30	33.67±0.29	46.23±0.29
K	187.80±0.34	321.85±0.34	457.56±0.34	592.68±0.33	727.69±0.34	2889±0.32
Cu	0.77±0.01	0.78±0.01	0.78±0.02	0.81±0.01	0.81±0.01	0.96±0.01

Explanations of types of flours in table 1

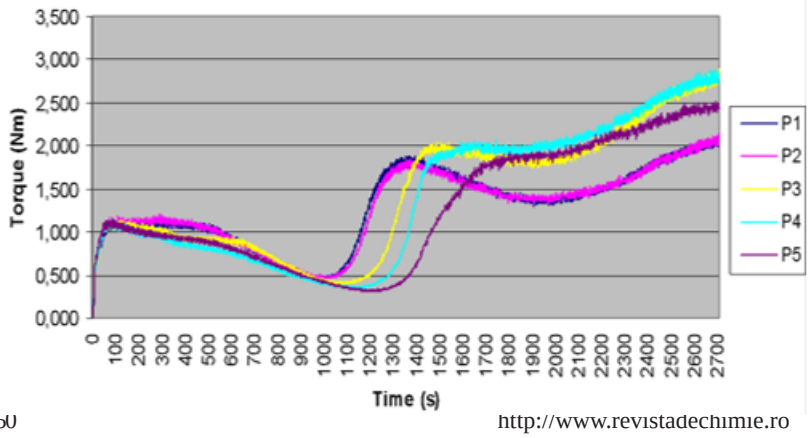

Fig.1. Mixolab torque curves (N·m) of wheat and wheat–tubers composite flours

Table 7

INFLUENCE ON MIXOLAB CHARACTERISTICS OF *H. TUBEROSUS* FLOUR ADDITION

Parameter	Abbreviation	P1	P2	P3	P4	P5
Water absorption %	CH	61	59	54	50.6	46.8
Stability min	ST	8.97	8.53	5.48	5.05	4.28
Maximum consistency during:						
phase 1 (N•m)	C1	1.11	1.14	1.09	1.08	1.1
	TC1	4.68	3.84	1.78	1.68	1.4
phase 2 (N•m)	C2	0.47	0.45	0.4	0.35	0.32
	TC2	16.27	16.8	17.6	18.6	20
phase 3 (N•m)	C3	1.79	1.83	1.98	1.99	0.53
	TC3	22.72	23.02	25.27	27.73	23
phase 4 (N•m)	C4	1.35	1.38	1.8	1.94	1.85
	TC4	33	32.05	31.8	30.03	30
phase 5 (N•m)	C5	2.05	2.07	2.45	2.77	2.8
	TC5	45	45	45	45	45

Explanations of types of flours in Table 1; explanations of TC1-TC5; C1-C5 in Table 2; CH – water absorption %; ST – stability time, min

Rheological properties of doughs mixtures

The rheological behaviours of wheat flour dough (P1) and of all four mixtures during the Mixolab test are illustrated in figure 1 and table 7.

Mixolab C1–C5 values of pure wheat dough (P1) were 1.10, 0.47, 1.79, 1.35 and 2.05 N•m, respectively. Similar behaviour was mentioned by Papouskova et al. [23] for three wheat varieties, with only small differences (C1–C5 averages 1.12, 0.46, 2.04, 1.76 and 2.44 N•m, respectively). As the percentage of the *H. tuberosus* tuber flour increases, the water absorption capacity and dough formation time (TC1) decrease (fig. 2). A low resistance of dough to mixing was noted. A decrease in consistency (C2), showing a higher softening under the effect of temperature, reveals some negative qualitative changes in flour protein composition, i.e. changes or dilution of gluten content.

Dough stability times ranged from 5.05 to 8.97 min, except for sample P5 (4.28 min,) (fig. 3). The lowest C3 was determined for pure wheat dough (P1) (table 5). The difference in C3 results between P1 and P2 samples was 0.04 N•m; thus, the influence of flour mixture used for dough was insignificant; the same applies for C2. As mentioned above, the C4 parameter corresponds to the stability of the starch gel formed (fig. 4). This parameter was strongly influenced by the amount of *H. tuberosus* flour used in the flour mix. For P1 and P2, the difference between C4 parameter values (1.35 N•m and, respectively, 1.38) is insignificant.

For the other samples, a gradual increase of the C4 parameter was noticed (1.8 for P3 and 1.94 for P4), except in the case of P5 where it decreased to 1.84.

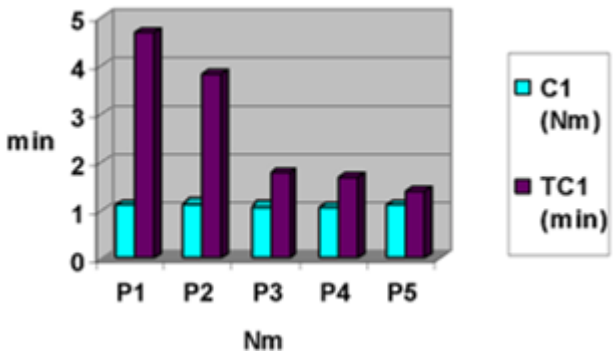

Fig. 2. Dough formation time

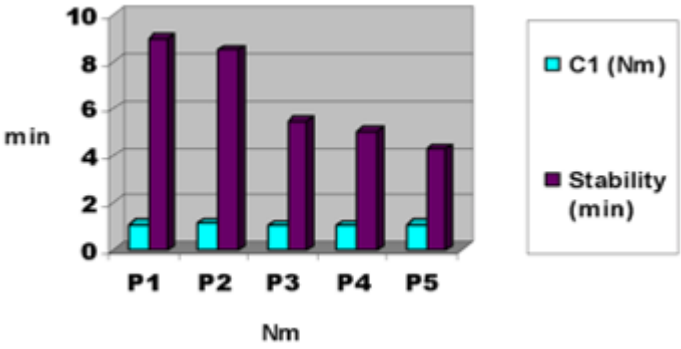

Fig. 3. Dough stability times

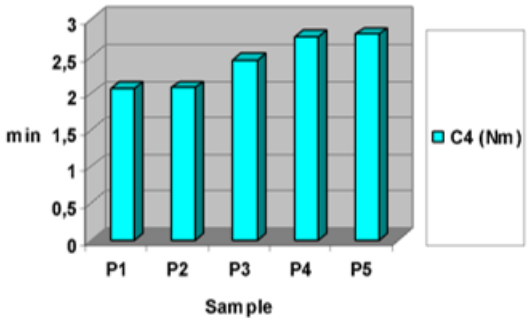

Fig. 4. Stability of starch gel

The retrogradation stage of starch (C5) in the analyzed wheat flour and wheat-tuber flour mixtures, demonstrated similar differences as the measurement for starch gel stability. It can be observed that differences in C5 between consecutive samples are not notable, but that the difference between P1 and P5 is considerable (2.05 and 2.80 N•m, respectively).

Bread properties

The final moisture content of bread depends on the absorption of water during dough formation and water loss during baking. From table 8, it is apparent that the addition of *H. tuberosus* flour has a significant effect on the moisture of the samples: P5 had the lowest moisture content (37.61) compared with the control (P1). The final bread volume depends on dough expansion during fermentation and baking, and on the ability of the matrix to stabilize the retained gas. The sample made from the mixture of wheat flour with 20% *H. tuberosus*, (P5), had a volume of 154 cm^3, compared to the P1 sample volume which was 384

Table 8

PHYSICOCHEMICAL RESULTS FOR THE EXPERIMENTAL BREAD SAMPLES

Sample	Mass kg	Volume cm^3	Porosity %	Elasticity %	Aroma	Moisture content %	Acidity, degree
P1	0.524	385	85.8	95	Pleasant taste and smell, specific to white bread	43.70	1.2
P2	0.540	226	72	92	Pleasant taste and smell specific to bread with a high degree of extraction	42.31	1.6
P3	0.550	174	57.8	81	Smell of artichoke, sticky when chewing	41.18	1.9
P4	0.557	163	57.2	80	Strong smell of artichoke, sticky when chewing	40.47	2.0
P5	0.559	154	53.47	75	Strong smell of artichoke, sticky when chewing	37.61	2.2

Table 9

SCORES OBTAINED FROM ORGANOLEPTIC EVALUATION OF BREAD SAMPLES USING THE *BREAD SCORE*

Sample/	Volume	Marginal crack height	Skin colour	Colour core	Porosity	Elasticity	Aroma	Total
P1	23	7	6	10	17	17	12	92
P2	14	4	6	9	15	15	10	73
P3	11	3	5	5	6	7	4	41
P4	10	3	5	5	5	6	4	38
P5	9	3	4	4	4	4	4	32

Explanations of types of flours in Table 1

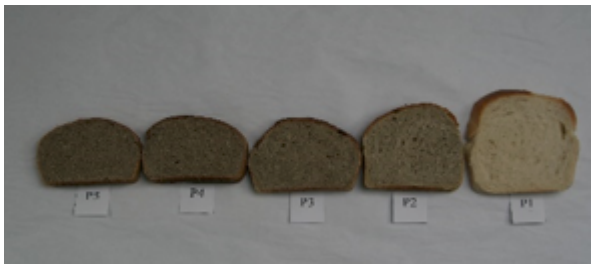

Fig. 5. Crumbs of bread enriched with different concentrations of Helianthus tuberosus (P1, P2, P3, P4,P5)

cm^3. This significant decrease is due to the dilution effect: soluble fibre affects gas retention as it interacts with the gluten network, but does not increase the gas production, resulting in a disrupted structure [24, 25].

These results seem to be correlated with the rheological data presented in table 7, as the specific volume decrease coincides with decreased consistency of the dough bread (C2). That means that the protein flour composition undergoes some negative qualitative changes, i.e. dilution of gluten content and changes in gluten structures. As it can be observed in table 8, there are major changes in all the parameters of bread samples with the highest concentration of *H. tuberosus* flour, when comparing them to P1 (100% wheat flour). The parameters of sample P2, the one with the lowest concentration of *H. tuberosus* flour, are far superior to the ones of the other flour mixtures.

In terms of acidity of the bread samples, the increase in percentage of *H. tuberosus* flour results in the increase of acidity up to 2.2 degrees, which is the typical value obtained for bread made from whole wheat.

According to the results obtained in porosity measurement experiments, it was noted that the high percentage of *H. tuberosus* flour did not allow gas formation and retention during baking, with visible consequences on bread porosity. However, the sample with the lowest content of *H. tuberosus* flour showed an acceptable porosity compared to that obtained from whole wheat bread. This is true for elasticity as well.

In figure 5 there are presented crumbs of bread enriched with different concentrations of *H. tuberosus* (P1, P2, P3, P4, P5). Our research results are confirmed by various studies, with the difference that these studies used inulin powder extracted from *H. tuberosus* flour [26-31].

These studies indicated that wheat bread can be enriched with inulin up to 2.5 g /100 g flour and still retain the quality attributes of conventional bread. Of note, in our work, the wheat flour mixture with 5% *H. tuberosus* contains about 3 g inulin per 100 g sample.

It can be seen in table 9 that wheat flour with 5% *H. tuberosus* flour is acceptable for making bread of similar organoleptic quality to whole-wheat flour bread. However, to improve the quality of the bread obtained from the flour mixture, it is necessary to choose a technology that improves both the formation and retention of gases and bread elasticity.

Conclusions

The chemical characterization performed in this study proved that Jerusalem artichoke (*H. tuberosus* L.) flour is a valuable source of nutritional components, mainly inulin and minerals.

The main conclusion in our study with respect to rheological properties of dough made from wheat flour and *H. tuberosus* flour was that the P2 sample (5 g *H. tuberosus* tuber flour added to 95 g wheat flour) retained suitable rheological parameters for obtaining bakery products of a good quality. After performing the baking test, it was observed that the best sensory and physicochemical values were obtained using an addition of 5% *H. tuberosus* tuber flour, and these were comparable to those of whole wheat bread.

This study provides useful information toward using *H. tuberosus* flour as source of functional ingredients in the bakery industry; in particular, this flour can be regarded as a valuable *source of fibre* (more than 3 g100 g^{-1}), according to Regulation 1924/2006.

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