Research Regarding Resistance Characteristics of Biscuits Assortment Using Cone Penetrometer

G.–A. Constantin, G. Voicu, E.–M. Stefan, P. Tudor, G. Paraschiv, M.–G. Munteanu

Abstract**—**In the activity of handling and transport of food products, the products may be subjected to mechanical stresses that may lead to their deterioration by deformation, breaking, or crushing. This is the case for biscuits, regardless of their type (gluten-free or sugary), the addition of ingredients or flour from which they are made. However, gluten-free biscuits have a higher mechanical resistance to breakage or crushing compared to easily shattered sugar biscuits (especially those for children). The paper presents the results of the experimental evaluation of the texture for four varieties of commercial biscuits, using the penetrometer equipped with needle cone at five different additional weights on the cone-rod. The assortments of biscuits tested in the laboratory were Petit Beurre, Picnic, and Maia (all three manufactured by RoStar, Romania) and Sultani diet biscuits, manufactured by Eti Burcak Sultani (Turkey, in packs of 138 g). For the four varieties of biscuits and the five additional weights (50, 77, 100, 150 and 177 g), the experimental data obtained were subjected to regression analysis in the MS Office Excel program, using Velon's relationship ($h = a \cdot \ln(t) + b$). The regression curves were analysed comparatively in order to identify possible differences and to highlight the variation of the penetration depth h, in relation to the time t. Based on the penetration depth between two-time intervals (every 5 seconds), the curves of variation of the penetration speed in relation to time were then drawn. It was found that Velon's law verifies the experimental data for all assortments of biscuits and for all five additional weights. The correlation coefficient R2 had in most of the analysed cases values over 0.850. The values recorded for the penetration depth were framed, in general, within 45-55 p.u. (penetrometric units) at an additional mass of 50 g, respectively between 155-168 p.u., at an additional mass of 177 g, at Petit Beurre biscuits. For Sultani diet biscuits, the values of the penetration depth were within the limits of 32-35 p.u., at an additional weight of 50 g and between 80-114 p.u., at an additional weight of 177g. The data presented in the paper can be used by both operators on the manufacturing technology flow, as well as by the traders of these food products, in order to establish the most efficient parametric of the working regimes (when packaging and handling).

Keywords**—**Biscuits resistance/texture, penetration depth, penetration velocity, sharp pin penetrometer.

I. Introduction

RESISTANCE characteristics at mechanical stresses, such as shear, bending or compression strengths, of biscuits, are closely related to the quality of flour and raw materials from which these are made. Also, manufacturing process (kneading, modelling and baking) and its basic parameters are important factors that determine the texture and resistance of biscuits.

On the mechanical strength and texture of biscuits few experimental studies have been conducted, most of them being carried on physicochemical and sensory properties [1]-[6].

Biscuits are bakery products with a high content of fat and sugar. Food ingredients can be added to their recipe in order to improve the physico-chemical properties [7].

Maia biscuits are made from wheat flour, sugar, oil and vanilla, have a round shape and are consumed, ordinarily, with milk. Physicochemical and sensory analyses of Maia type biscuits, performed on eight commercial varieties, have showed that they have minor differences, in relation to ash content, although presents significant differences in moisture and fat content [7].

It was found that the uniaxial compression test results performed on biscuits' hard dough in order to determine the biaxial extensional viscosity are heavily dependent on the speed of compression [8].

In [9] the authors have tested qualities of biscuits made from wheat flour mixed with various amounts of flour obtained from African breadfruit. There were significant differences in relation to smell, taste, texture, flavour and colour of biscuits closely related to the content of added African breadfruit flour. Regarding the biscuits break strength, it was in the 139-299.8 kg domain.

Textural attributes of commercial biscuits and the effect of relative humidity on their quality were recorded by [10]. There were investigated two types of semi-sweet biscuits ("Maria" and „Petit Beurre"), both in terms of textural variability, but also the influence of relative humidity storage on texture, porosity and colour of biscuits. It was found that the variation of the relative humidity within the limits 11-32% has no significant influence on texture of biscuits, but the porosity increased with moisture content. However, there is some variation of texture depending on location of puncturing (centre or periphery of biscuits).

In [4], on the textural characteristics of biscuits prepared from refined wheat flour (63.2-96.8%) and millet flour, the authors found that increasing the amount of refined wheat leads to lower hardness. Also, extending the baking time from 3.3 to 6.7 min reduces the hardness and shear strength. Instead, rising baking temperatures (in limits 166.6-183.4 ^{o}C) produces an increase in crispness and a decrease in toughness and resistance to cutting. The optimum processing conditions were obtained for 90% refined wheat flour, 6 min. baking time

G.A. Constantin, Gh. Voicu, E.M. Stefan, P. Tudor, G. Paraschiv, and M.G. Munteanu are from University Politehnica of Bucharest, Faculty of Biotechnical Systems Engineering, Biotechnical Systems Department 313 Splaiul Independenței, District 6, 060042, Bucharest, Romania (phone: +4021.4029648, fax: +4021.318.10.18, e-mail: constantin.gabriel.alex@gmail.com, ghvoicu_2005 @yahoo.com, stefanelenamadalina@gmail.com, paula.tudor@upb.ro, paraschiv2005@yahoo.com, munteanumaya@yahoo.com).

and 170 °C baking temperature. The values obtained for crispness, hardness and cutting strength ERE 45, 0.3 and 27.2 N respective.

If buckwheat flour (10, 20, 30, 40%) is added to the refined wheat flour, the fracture strength decreases [2]. Compared with refined wheat flour, absorption capacity of buckwheat flour was lower, but oil absorption and foaming capacity was significantly higher. Also, it was found that the biscuits with 20 and 30% buckwheat flour achieved a better overall acceptability score.

The authors [2] and [11] found that biscuits enriched with buckwheat flour have a higher spread, durability and fracturability. The addition of rye flour had an improving effect on the dough (decreased hardness and increased cohesion), but buckwheat was the ingredient that most improved qualities of the dough and biscuits.

Sharp pin penetrometer can be used to test textural characteristics of various agricultural and food products. It was used in [12] and [13] for testing rheological properties of the dough prepared from different types of flour with different contents of ash, using a standard sharp pin from Plexiglas and four additional weights. The validity of Velon's law was tested, and a good correlation was found with the experimental data ($R^2 \geq 0.991$), especially for additional weights of 14.1 g and 19.8 g.

For doughs of biscuits, Manohar and Rao [14] used a penetrometer equipped with a metal disc, in order to test their rheological properties at different amounts of added water. Elastic recovery, that indicates dough development, was always higher for hard wheat flour doughs, comparative with soft wheat flour doughs, in all conditions.

In our paper are presented the results of penetration with sharp pin stress tests, of four types of biscuits at five additional weights. The validity of Velon's law was tested and the curves of variation of the penetration speed with time were highlighted.

II. Material and Method

Laboratory tests were carried out on types of semi-sweet biscuits or dietetic, three varieties produced by RoStar Romania (Bucharest) – Petit Beurre, Picnic and Maia and an assortment of dietary biscuits (138 g package), manufactured by Eti Burcak Sultani, commercially available.

RoStar biscuits are made from wheat flour, invert sugar, non-hydrogenated vegetable fat, raising agents (sodium bicarbonate and ammonium bicarbonate), iodized salt, emulsifier (soy lecithin), preservative (sodium metabisulfite), and acidifying (citric acid). Sugar and fat content are different from brand to brand. Furthermore, Petit Beurre biscuits (100 g) contain artificial flavour (etivaniline), Picnic biscuits contain natural vanilla powder 0.02%, and Maia biscuits contain about 5% honey. Sultani biscuits are prepared from mixtures of wheat white flour with whole wheat flour (2.6% bran), vegetable fat, sugar, raisins 8%, raising agents (ammonium hydrogen carbonate, sodium hydrogen carbonate), malt extract, salt, emulsifiers and flavours.

After measurements, it has been found that the thickness of the Petit Beurre biscuits has a range of values between 6.28 and 7.52 mm, with a mass between 3.78 and 4.14 g (deviations ± 3.1–7.5%), while Picnic biscuits have thickness between 5.48 and 6.34 mm and a mass between 15.2 and 15.9 g, and Maia biscuits have thickness between 5.50 and 6.56 mm and a mass within range 24.4-29.0 g.

In the experiments was used a semi-automatic penetrometer SDM Apparechi Scientifici Torino, with penetration instrument type hardened stainless steel needle, with a diameter of 3.2 mm (ASTMD5). On the stem of the sharp pin was added five additional weights of different weight 50, 77, 100, 150, 177 g.

The tests were made in the central part of the biscuit, in an area visible homogeneous, the results presented in this paper are the average of three measurements on different biscuits (from the same package).

The depth of penetration was measured (in penetrometer units, u.p. – 1 u.p. = 0.1 mm), for a probationary time of 60 s, at a time interval of 5 s.

Biscuit subjected to the test was placed over the other two biscuits (from the same package) to avoid passing the needle beyond and propping up by table of the device.

In Fig. 1 are presented an overview of the device and needle used in the experimental tests.

III. Results and Discussion

The results obtained in the experiments concerning the variation in the penetration depth in function of time, for five additional weights, are shown in Table I.

For each type of biscuit were plotted charts of variation of experimental data (penetration depth vs. time), and they were tested by regression analysis, in program MS Excel, with the distribution law of Velon, expressed by:

$$h = a\ln(t) + b \quad (1)$$

where: a and b are experimental coefficients, determined from the experimental data; b coefficient depends on the product texture which can be taken as a measure of this characteristic, [13].

Penetration velocity of the penetrometer needle v_c, in function of time, is obtained from (1), deriving against time:

$$v_c = \frac{dh}{dt} = \frac{a}{t} \quad (2)$$

Relation (2) is hyperbolic type and show significant variation of velocity at the beginning and insignificant by the end of penetration.

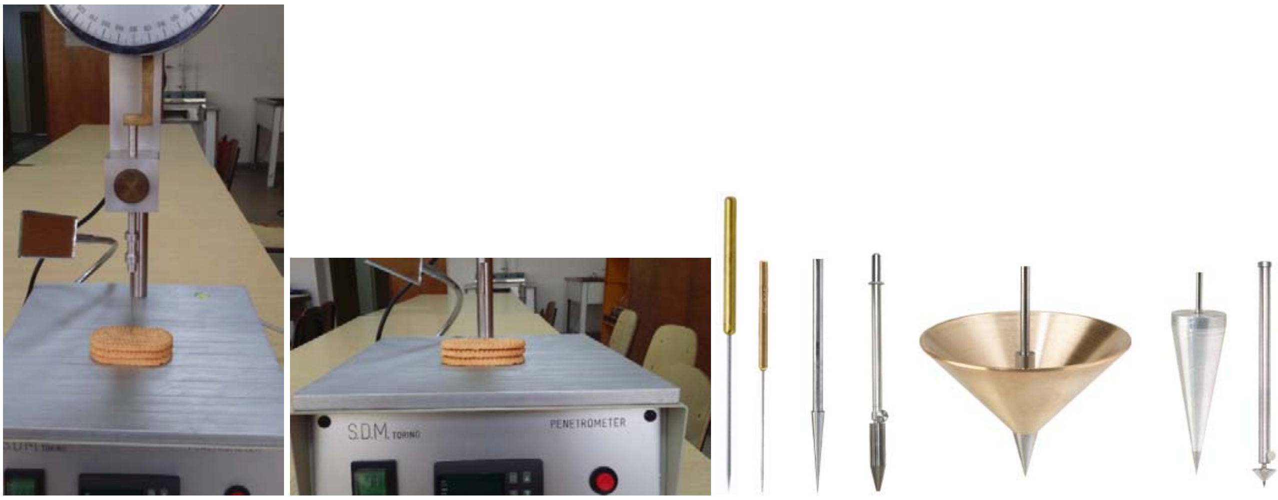

Fig. 1 Sharp pin penetrometer and needle used in the experimental tests, respective types of cones used in penetration tests for food products

TABLE I
THE CONE PENETRATION DEPTHS MEAN VALUES H (U.P.) VS. TIME T (S) FOR THE FOUR BISCUIT TYPES

	Petit Beurre					Picnic					Sultani					Maia				
t, s	50 g	77 g	100 g	150 g	177 g	50 g	77 g	100 g	150 g	177 g	50 g	77 g	100 g	150 g	177 g	50 g	77 g	100 g	150 g	177 g
5	45	72	83	91	155	32	48	75	82	130	32	42	50	73	80	28	41	45	56	64
10	47	74	86	93	158	34	50	77	87	132	33	43	55	75	84	29	43	46	59	67
15	48	78	87	95	160	34	51	78	92	137	34	44	55	77	88	30	44	47	60	68
20	48	78	89	100	162	35	53	81	102	139	34	46	56	78	89	30	44	48	61	69
25	49	79	90	104	163	35	54	82	104	142	34	47	57	80	100	31	44	48	62	73
30	49	80	91	114	164	36	55	84	106	143	34	49	58	82	106	31	44	50	63	81
35	49	83	92	124	165	37	56	86	106	144	34	51	58	83	113	31	44	51	64	84
40	50	85	93	126	166	37	56	88	106	145	34	51	59	85	114	32	45	51	65	85
45	51	86	94	131	166	38	57	89	111	146	34	52	60	87	114	33	45	51	66	87
50	52	87	95	140	167	39	57	90	111	147	35	53	60	88	114	34	45	51	66	99
55	53	88	97	143	167	39	57	92	112	147	35	53	61	90	114	34	46	51	66	100
60	54	88	99	145	168	39	58	93	113	147	35	53	61	92	114	34	46	51	67	100

According to the considerations from [14]-[16], at the equilibrium state of the cone corresponding to the maximum depth of penetration, the relation is found:

$$P = K_{\alpha} \cdot h_{\max}^{2} \cdot \tau_{c} \quad (3)$$

where: P is the pressing force (own weight), in (N); h_{max} – maximum depth of penetration of the cone, in (m); τ_c– shear limit at flow of the dough, in (Pa); K_α – constant of the cone, which depends only on the angle at the apex of the cone.

Examining data from Table I and curves from Fig. 2 in relation to the experimental points shows that, for the four types of biscuits researched and five additional weights, experimental data are well described by the law of Velon, because $R^2 \geq 0.835$, in all cases. Also, it reveals a significant enough difference between the values of the penetration depth, for each of the five additional weights, depths being greater at higher additional weights, as would be natural.

We may add that at biscuits Maia type, with honey, the depth of penetration is much smaller, at the same additional weight, than Picnic biscuits and especially Petit Beurre, although they are manufactured by the same company. If at Petit Beurre biscuits, the depth of penetration is within the range 155-168 u.p., at an additional weight of 177 g, at Picnic biscuits, penetration depth varies in the range 130-147 u.p., while at Maia biscuits, depth penetration is in the range 64-100 u.p., at the same additional weight. The increasing trend is kept, within the same limits at all sorts of biscuits.

At assortment of biscuits Sultani, at an additional weight on the stem of the cone of 177 g, limits of variation for the penetration depth are 80-114 u.p.

The same trends and allure of variation curves are meeting at the other additional weights, a very small intersection of the curves being observed at Petit Beure biscuits, at additional weights of 150 and 177 g (but it cannot ascribe on the textural characteristics variation, but rather can be taken at an totally random variation).

For the same assortment of biscuits, penetration depth variation with time, for the five additional weights can be easily seen in Fig. 2. Further, if penetration velocity variation of sharp pin in biscuit in function of time is of hyperbolic type was researched (2).

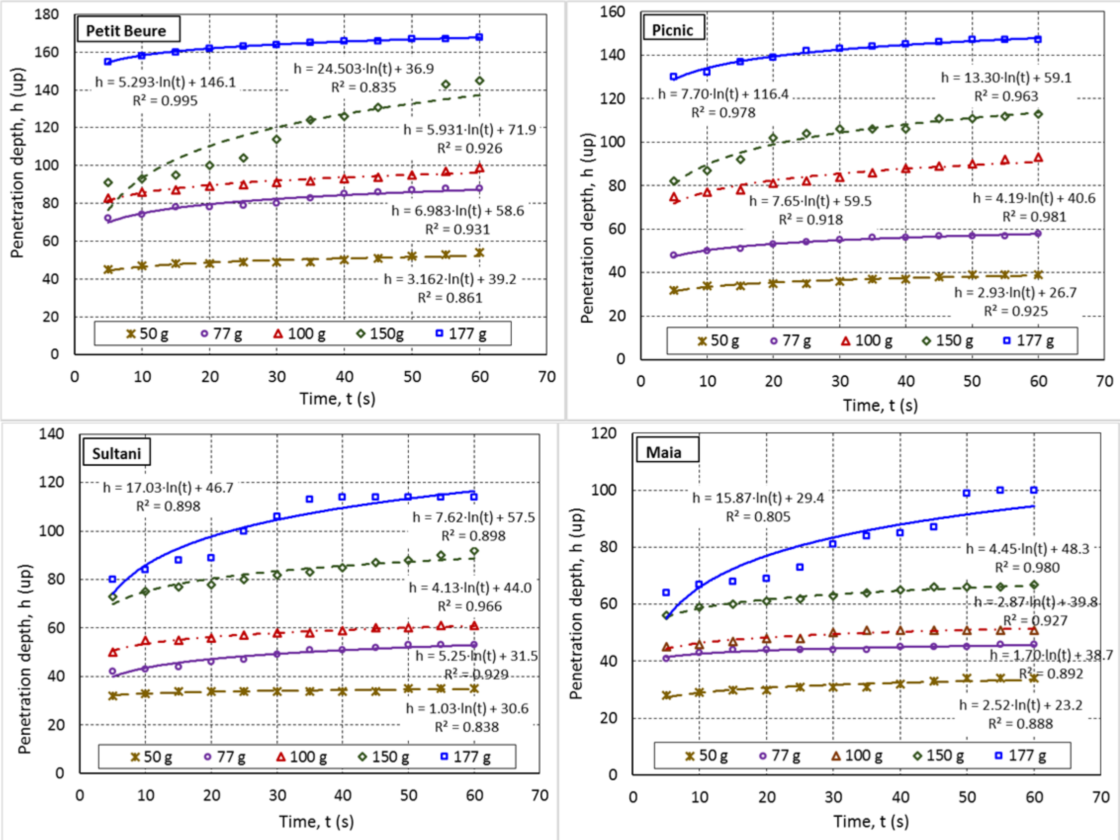

Fig. 2 The variation curves of penetration depth h (u.p.) vs. time t (s) for the four types of biscuits analysed, for the five additional weights used, obtained by regression analysis of experimental data with the law of Velon (1)

Since the data relating to depth of penetration were recorded at intervals $\Delta t = 5$ s, it was possible to calculate the average velocity values v_{mi} at every interval:

$$v_{mi} = \frac{h_{i+1} - h_i}{\Delta t} \quad (4)$$

Values assignable to moments t_{mi} corresponding to middle of each interval, namely:

$$t_{mi} = \frac{t_i + t_{i+1}}{2} = t_i + \frac{\Delta t}{2} \quad (5)$$

where: h_i, h_{i+1} are penetration depths corresponding to time moments t_i, t_{i+1} respective.

During the measurements for each sample were obtained experimental value pairs (t_{mi}, v_{mi}), for which was researched the validity of their description by hyperbolic function type:

$$v_c = \frac{\alpha}{t} + \beta \quad (6)$$

Values of α and β coefficients found by nonlinear regression with measurements data for the four types of biscuits, using computing program MicroCal Origin 8.0, together with the values of the correlation coefficients R^2, as well as concordance coefficient values χ^2, are shown in Table II. In Fig. 3 are shown curves described by (6) for coefficient values α and β given in Table III, in relation to the experimental points relating to needle penetration velocity variation in biscuit in function of time, for all experimental situations. These variations are well described by hyperbolic type function (6), because $R^2 \geq 0.856$ and $\chi^2 \leq 2.1$ (in over 85% of the cases analysed).

Since the β coefficient values are sufficiently close to zero then they can be neglected in the field of experimentation, so that the penetration velocity in function of time can be described, admissibly, through (4) obtained from theoretical analysis (2).

If at beginning we can consider a penetration velocity between 9-31u.p./s, at Petit Beure biscuits, for five additional weights (50-177 g), at the end of the process (after 60 s), penetration velocity is very small (respective between 0-0.2 u.p./s, at all types of biscuits). At Picnic biscuits, penetration velocity (at the beginning of the process) has values between 6.4-26 u.p./s, while at Sultani biscuits this is of 6.4-16 u.p./s, and at Maia biscuits between 5.6-12.8 u.p./s. shorter, the higher the drying temperature, the allure of the drying curves being preserved. Furthermore, the granulation of the grinder influences the drying and the final value of the humidity.

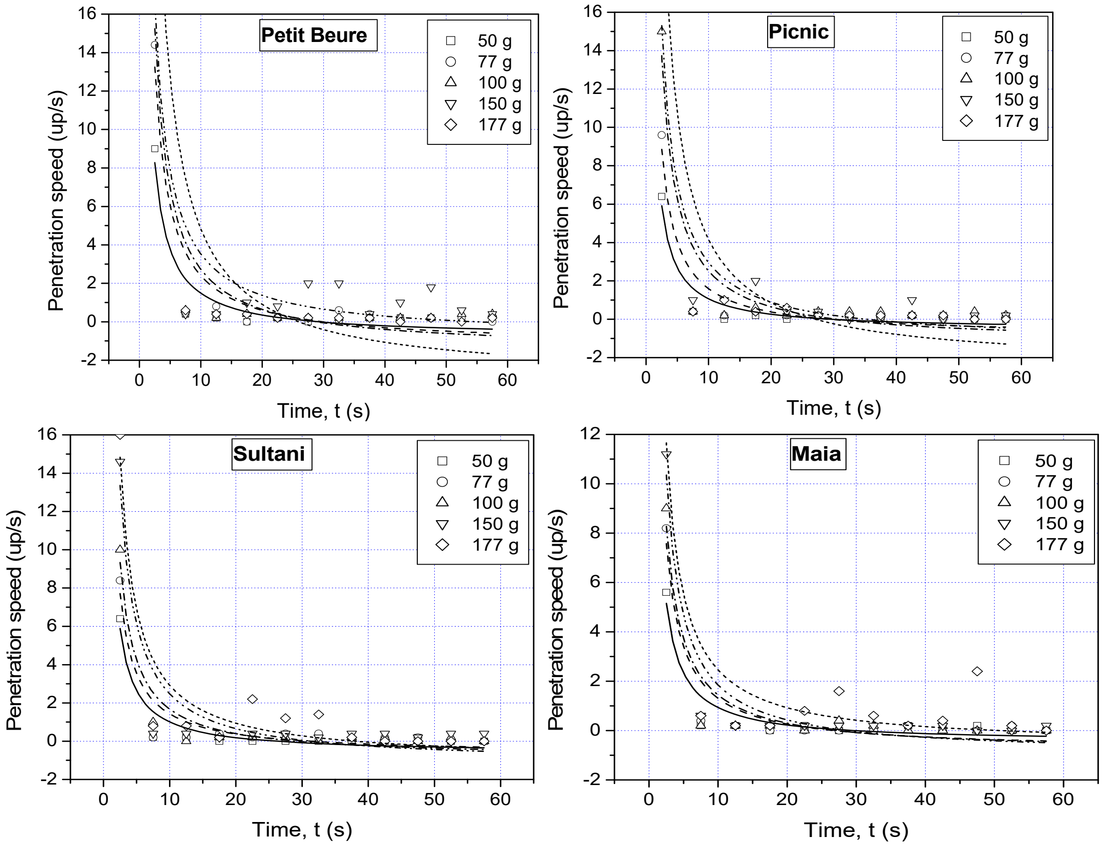

Fig. 3 Comparison of cone penetration velocity v_c(up/s) vs. time t(s) for the four biscuit types and five additional weights used in research

TABLE II
COEFFICIENTS α AND β VALUES, GIVEN BY (6), FOR THE FOUR TYPES OF BISCUITS AND FIVE ADDITIONAL WEIGHTS, TOGETHER WITH VALUES OF CORRELATION COEFFICIENT R^2 AND FITTING COEFFICIENT χ^2, RESPECTIVELY

Additional weight, g	Biscuit type	α	β	R^2	χ^2	Biscuit type	α	β	R^2	χ^2
50		22.632	-0.778	0.915	0.611		16.300	-0.625	0.920	0.296
77		36.149	-1.214	0.915	1.568		20.956	-0.670	0.909	0.563
100	Petit Beure	41.704	-1.442	0.913	2.123	Sultani	25.530	-0.876	0.940	0.535
150		43.193	-0.786	0.866	3.707		36.301	-1.158	0.906	1.755
177		78.686	-3.034	0.914	7.477		39.670	-1.041	0.907	2.070
50		16.151	-0.548	0.922	0.284		14.065	-0.476	0.913	0.241
77		24.222	-0.829	0.922	0.636		20.894	-0.783	0.923	0.455
100	Picnic	37.403	-1.223	0.907	1.834	Maia	22.785	-0.839	0.915	0.615
150		41.182	-1.170	0.929	1.656		28.337	-0.984	0.925	0.830
177		65.818	-2.430	0.916	5.096		30.649	-0.606	0.856	2.019

From the analysis of curves from Fig. 3, rapid variation of needle penetration velocity in biscuit is found, at the beginning of process, after which, although the downward trend is kept, this velocity variation is insignificant, which shows a strong texture of the biscuit, especially in its centre. Thus, if at the surface biscuit has a weaker texture, with a lower penetration resistance, beyond the surface zone; the texture of the biscuit exhibits a relatively high resistance to penetration. The zone from the surface, in which penetrometer needle penetrates easily, is lower for small additional weights, without exceeding the thickness of a biscuit, but starting from 77-100 g, especially at Petit Beure and Picnic biscuits, penetrometer needle penetrates at a high depth from the beginning and exceeds the thickness of a biscuit. It can be said, so, that the penetration resistance is less for biscuits with less sugar content and higher at biscuits with honey Maia. Also, we can say that firmness of baked biscuit (and its texture) can highlight using sharp pin penetrometer, penetration depth being closely related to ingredients added to the recipe and their quantity.

IV. CONCLUSION

The most significant results to characterize the texture of food products are obtained by the depth of penetration of a standard needle, with a diameter of 3.2 mm and an individual pressing mass of 14.1 g. The validity of the Velon law (1) of four types of biscuits was tested, finding that it keeps for all these, irrespective of added weight on the penetration cone stem. It has been shown that values of „b" coefficient from law of Velon varies with the texture of product, being directly linked to its structure which is determined by the added ingredients in the recipe and their quantity, i.e. values of „b" coefficients, can serve as a measure of the change texture, from one product to another.

It was observed that sugary biscuits (Petit Beure and Picnic) have a greater penetration depth compared to gluten biscuits (Maia and Sultani) leading to a lower tensile strength than these. If the values recorded for penetration depth were within range 45-54 u.p. at an additional mass of 50 g, respective between 155-168 u.p., at an additional mass of 177 g, at Petit Beurre biscuits, at dietary biscuits Sultani, the depth of penetration values were in range 32-35 u.p., at an pressing weight of 50 g, respectively in the range of 80-114 u.p., at an pressing weight of 177 g.

Most sensitive at pressing were Petit Beure biscuits, followed in order by Picnic, Sultani and Maia biscuits. For Maia biscuits, the penetration depth was 28-34 u.p., at an additional mass of 50 g, gradually increasing at penetration depths between 64-100 u.p. for a pressing weight of 177 g. We can choose a cone penetration length of 30–40 s for which on basis of the penetration depth to obtain the most significant information for texture due to the biscuits recipe used.

As regards the penetration velocity, for biscuits with different manufacturing recipes, under conditions in which the others parameters of technological process is kept (baking time and temperature), it decreases hyperbolic with the pressing weight of penetrometer sharp pin, but also depends on the recipe. Penetration velocity was for all kinds of biscuits very high at the beginning of penetration process of needle in biscuits, deducting hyperbolic after first 5 seconds and maintaining a very discreet variation after this period. These data are useful in the development of future research in this area contributing to elaboration of adequate testing protocols for biscuits, both in terms of content of recipe ingredients, but also of processing regimes parameters of the products.

Acknowledgment

The work has been funded by Ministry of National Education and Research through the Executive Agency for Higher Education, Research, Development and Innovation Funding, within the project entitled "Sustainable development of the base of agromechanical applications in gardens, solariums, vineyards and orchards (DEZDURPRA)", CNFIS-FDI-2020-0184, and project FSS Engineer in Europe III.

References

[1] N.U. Arisa, A.O. A.E.Adelekan, A.E. Alamu and E.J. Ogunfowora, "Effect of pretreatment of plantain (*Musa parasidiaca*) flour on the pasting and sensory characteristics of Biscuit Product", *Pakistan Journal of Food Sciences*, 23(1), 43-51, 2013.

[2] S.Y Baljeet, B.Y. Ritika and L.Y. Roshan, "Studies on functional properties and incorporation of buckwheat flour for biscuit making", *International Food Research Journal*, 17, 1067-1076, 2010.

[3] A. Bukya, K.V. Sunooj, and A.S. Babu, "Standardization and evaluation of physical, textural and organoleptic properties of chicken biscuits", *International Journal of Advanced Research*, Vol. 1, Iss.6, 163-168, 2013.

[4] S.K. Chakraborty, B.K. Kumbhar, S. Chakraborty, P. Yadav, "Influence of processing parameters on textural characteristics and overall acceptability of millet enriched biscuits using response surface methodology", *Journal of Food Science and Technology*, Vol. 48, Iss. 2, 167-174, 2011.

[5] P.M.Ganorkar and R.K.Jain, "Effect of flaxseed incorporation on physical, sensorial, textural and chemical attributes of cookies", *International Food Research Journal*, 21(4), 1515-1521, 2014.

[6] O.A. Olaoye, A.A. Onilude and C.O Oladoye, "Breadfruit flour in biscuit making: effects on product quality", *African Journal of Food Science*, 020-023, 2007.

[7] D. Pereira, P.M.R. Correia, R.P.F. Guiné, "Analysis of the physical-chemical and sensorial properties of Maria type cookies", *Acta Chimica Slovaca*, Vol. 6, no. 2, 269—280, 2013.

[8] L. Piazza and A. Schiraldi, "Correlation between fracture of semi-sweet hard biscuits and dough viscoelastic properties", *Journal of Texture Studies*, Vol. 28, Iss. 5, 523–541, 1997.

[9] H. O. Agu, J. A. Ayo, A. M. Paul and F. Folorunsho, "Quality characteristics of biscuits made from wheat and African breadfruit (*Treculia africana*)", *Nigerian Food Journal*, Vol. 25, no. 2, 19-27, 2007.

[10] I.G. Mandala, C.A. Ioannou and A.E. Kostaropoulos, "Textural attributes of commercial biscuits. Effect of relative humidity on their quality", *International Journal of Food Science & Technology*, Vol. 41, Iss. 7, 782–789, 2006.

[11] B. Filipcev, O. Simurina, M. Bodroza-Solarov, M. Vujakovic, "Evaluation of physical, textural and microstructural properties of dough and honey biscuits enriched with buckwheat and rye", *Chemical Industry & Chemical Engineering Quaterly,* 17(3), 291−298, 2011.

[12] T. Casandroiu, Gh. Voicu, Cr. Mieila, "Experimentally researches concerning rheological behaviour of the wheat flour dough under the dead load of a cone penetrator", *Bul. Institute Polytechnic of Iasi*, Romania, Tom LII (LVI), Fasc. 6C, Section Machinery building, 257-267, 2006.

[13] Casandroiu, Gh. Voicu, Chih Li-Hua I., "Researches regarding the cone penetration for rheological behaviour characterization of some wheat flour doughs", *Scientific Bulletin, University Politehnica of Buchares*t, Romania, Series D: Mechanical Engineering, Vol.69, no.4, 3-18, 2007.

[14] S. Manohar, and H. Rao, 1992 "Use of a penetrometer for measuring rheological characteristics of biscuit dough", *Cereal Chemistry*, 69 (6). 619-623 ; 10, 1992

[15] Iu.A. Macihin, S.A. Macihin, Inginernaia reologhia piscevâh materialov, Legcaia i piscevaia promsti, Moskva, 1981.

[16] D.N. Yadav, N. Thakur, K.V. Sunooj, "Effect of partially de-oiled peanut meal flour (DPMF) on the nutritional, textural, organoleptic and physico chemical properties of biscuits", *Food and Nutrition Sciences*, no.3, 471-476, 2012.