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Halogen drying kinetics of some vegan crackers as fortified food products

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Abstract

In the present study the kinetics of halogen drying process of various vegan crackers used as fortified food products have been performed. Six vegan cracker samples containing various active ingredients such as whole grain wheat, rye, oat, or spelt flour, rice, chickpeas or buckwheat flour, wheat bran, yeast or oat flakes, expanded millet, psyllium or turmeric powder, dried sour cherries, concentrated grape juice, flaxseeds, white sesame, hemp, chia, poppy, pumpkin, black caraway seeds, walnuts, coconut oil, rosemary, basil, lavender or lemon essential oils have been used. The moisture content as well as the drying kinetics were evaluated using the halogen drying technique. A temperature of 120 °C and a "strobe" time range of 30 s were set for the Partner WPS 210S halogen drying equipment. The overall moisture content of the vegan crackers was in the range of 6.32-7.96%, with a highest value for crackers with turmeric and psyllium addition, 7.96 (±0.45)%. The drying time vary from 11.17 (±2.02) min to 40.5 (±14.0) min, while the drying process has very different behavior. This behavior indicates how the "surface" and "strongly retained" water molecules are released from the food matrix. The kinetics of the drying process can quantify this aspect through the drying rates on specific time ranges. Three time ranges of 0-30 s, ½ - 1 ½ min and 1 ½ - 20 min (or more) have been selected. The drying rates significantly vary on the first interval, from 0.057 (±0.002) %/s for chickpeas, buckwheat and rice flour based crackers to 0.088 (±0.005) %/s for the pumpkin and black caraway seeds based crackers, while this rate on the second and third time ranges had variations of 0.0075-0.0099 %/s and 0.0008-0.0017 %/s, respectively. A qualitative correlation between the types of water molecules from the food matrix with the drying kinetic parameters have been established for such fortified food products.

Keywords: halogen drying, drying kinetics, moisture, water content, fortified food products, crackers, biscuits, fruit and cereal flour, spices essential oils, oily seeds

1. Introduction

Functional food are extensively studied in the last years due to the request of food products having positive influence to the human health. In this regard, functional food products must have beneficial effects on one or more targets in the body. Three types of functional food exist: (1) a natural food product, (2) a food product enhanced with a beneficial component (or from where a deleterious component has been removed), and (3) a food product where one or more components were modified [1]. Many types of food products can be

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enhanced in order to obtain functional or fortified food products. They belong to soft drinks, cereal and baby food products, baked and confectionery products, meat based products, and especially dairy products (such as yoghurts and other fermented products) [2-8]. On the other hand, there are many sources and health targets for these functional food products: vitamin and mineral fortification, dietary fiber, cholesterol reduction, oils and fats, prebiotics and probiotics, antioxidants, phytochemicals, herbs and spices. They have potential against infections, gastrointestinal disorders, osteoporosis, various types of cancer, colonic disorders, hypertension, coronary heart diseases, and even dental caries [9-13].

Functional confectionery is widely studied for enhancing these products by vitamins and minerals, soluble and insoluble fibers, plant extracts, pre- and probiotics, and other phytochemicals. Among these, biscuits or crackers are generally enhanced in order to obtain functional or fortified confectionery food products [14-16].

The main goal of the study was the evaluation of the kinetics of halogen drying process of various vegan crackers based on whole grain wheat, rye, oat, or spelt flour, rice, chickpeas or buckwheat flour, wheat bran, yeast or oat flakes, expanded millet, psyllium or turmeric powder, dried sour cherries, concentrated grape juice, flaxseeds, white sesame, hemp, chia, poppy pumpkin, black caraway seeds, walnuts, coconut oil, rosemary, basil, lavender or lemon essential oils, used as fortified food products.

2. Materials and Method

2.1. Materials

Crackers samples were obtained by classical recipes and contain various natural ingredients that provide specific functionalities for every sample. The following vegan crackers have been used in this study: *TuPsy* – biscuits with turmeric and psyllium (whole grain wheat flour, concentrated grape juice, whole grain rye flour, coconut oil, psyllium (10%), oat flakes, wheat bran, poppy seeds, flaxseeds, turmeric powder (1%)), *CpBwRc* – biscuits with chickpeas, buckwheat and rice (chickpeas flour (26%), concentrated grape juice, rice flour (20%), buckwheat flour (15%), white sesame seeds, coconut oil, natural essential lemon oil), *WnBsl* – biscuits with walnuts and basil (whole grain wheat flour, whole grain oat flour, concentrated grape juice, coconut oil, walnuts (10%), rice flour, basil (2%)), *LvMil* – biscuits with lavender and millet (whole grain wheat flour, whole grain spelt flour, concentrated grape juice, coconut oil, dried sour cherries (5%), expanded millet (3%), natural lavender oil (2%)), *HmChi* – crackers with hemp seeds and chia seeds (whole grain wheat flour, whole grain spelt flour, coconut oil, buckwheat flour, hemp seeds (12%), flaxseeds, chia seeds (%), sea salt, rosemary), and *PkBcw* – crackers with pumpkin and black caraway seeds (whole grain wheat flour, whole grain spelt flour, coconut oil, pumpkin seeds (9%), yeast flakes, white sesame seeds, sea salts without iodine addition, black caraway seeds, apple vinegar). The energetic values of these cracker samples vary from 1589 kJ/100 g for *CpBwRc* to 2025 kJ/100 g for *HmChi* sample.

2.2. Determination of moisture content

The moisture content of the vegan cracker samples have been determined using the halogen drying technique. A Partner WPS 210S equipment (maximum capacity of 210 g, accuracy of 0.001 g / 0.01 %, two halogen lamps of 300 W, heating time up to 100 °C of one minute, temperature range of 50-160 °C, temperature step of 1 °C, and maximum heating time of 10 hours, Radwag Intelligent Weighing Technology, Inc.) have been used. Grounded sample masses of about 4.5 (±0.5) g had weighted and the mass variation during halogen drying was monitored at 120 °C using a "strobe" time range of 30 s. All determinations were made in triplicate.

2.3. Kinetics of drying process

The kinetics of the halogen drying process was determined as the drying rate expressed as the moisture loss in a specified time range (%/s). Three pseudolinear variation of the moisture content have been identified: (1) 0-30 s, (2) 30-400 s and (3) >400 s. The first time range was attributed to the loss of "surface" water molecules, while the second and third ranges correspond to the release of "strongly retained" water molecules.

2.4. Statistical and correlational analysis

Classical statistical analysis of variance (ANOVA) have been applied for handling of moisture content data obtained for triplicate analysis. Mean values and standard deviations for these three multiplicates have been calculated. On the other hand, non-linear and linear regression of the variation of actual moisture content in time at various time ranges, and the quality of equations were evaluated by the *Pearson* correlational coefficient (r^2), the standard error for coefficients, error of estimate and *F*-Fischer coefficient of the correlational equations.

3. Results and Discussion

3.1. Moisture content of vegan crackers

The moisture content of food products is an important index of the quality, especially for cereal based food products [17-20]. Water is the main volatile compound in such food products. Thus, the moisture content can be considered to be equal with the water content, because the other volatile content (such as flavoring compounds) is negligible. The quality and stability of a cereal based food product are closely related to the water activity, which is the ratio between the actual water vapor pressure above the product and the water vapor pressure at saturation for given conditions [6,17,21]. A water activity higher than 0.91 can favor the growing of bacteria, while a water activity higher than 0.7 can favor the growing of fungi.

Various methods for the determination of water or moisture content exists. There are direct methods, which are directly related to the determination of water content (e.g., separation by distillation, evaporation on drying, selective chemical reactions involving water), and indirect methods that allows water determination on the basis of measuring sample parameters indirectly related to water content (low-resolution nuclear magnetic resonance or near infrared spectroscopy). Moreover, combined techniques for water determination are also used [18,20].

The drying kinetics can be qualitatively correlated with the water activity of a food product because the way of bonding of water molecules into the food matrix influence both drying rate and water vapor pressure.

Halogen drying is an appropriate method for moisture determination of cereal flour based confectionery products because the drying process can be continuously monitored at a previously established and well controlled temperature. Food products containing cereal flour need higher temperature for drying due to the fact that gluten strongly retain water molecules inside the food matrix. Consequently, the drying temperature was set at 120 °C, while the drying time vary in a wide range, until no mass change was observed for at least 1 ½ minutes. This drying time was shorter for samples containing pumpkin and black caraway seeds, as well as hemp and chia seeds (540-780 s and 860-960 s, respectively) and much longer for samples containing other cereal flours (e.g., chickpeas, buckwheat and rice, with a drying time of 1470-3120 s, Table 1, Figure 1).

The moisture content of cracker samples is in a narrow range of 6.32-7.96%. The lowest value was obtained for the cracker sample with walnuts and basil, code *WnBsl*, and samples with hemp and chia seeds, code *HmChi*, with a mean value of 6.32 (±0.10) %, while the highest value was determined for the sample with turmeric and psyllium powder, code *TuChi* - 7.96 (±0.45) % (Table 1). However, the accuracy of all determinations was relatively high, the standard deviations for the triplicate analysis being (±0.1 ÷ ±0.92) %.

Table 1. Moisture content of all crackers samples, determined by halogen drying method (data for triplicate analysis and mean values ± standard deviation)

Nº	Code	Moisture content (%)
1a	*TuPsy(1)*	7.436
1b	*TuPsy(2)*	8.255
1c	*TuPsy(3)*	8.173
1	***TuPsy* ± SD**	**7.955 ± 0.451**
2a	*CpBwRc(1)*	8.682
2b	*CpBwRc(2)*	7.547
2c	*CpBwRc(3)*	6.863
2	***CpBwRc* ± SD**	**7.697 ± 0.919**
3a	*WnBsl(1)*	6.372
3b	*WnBsl(2)*	6.218
3c	*WnBsl(3)*	6.399
3	***WnBsl* ± SD**	**6.330 ± 0.098**
4a	*LvMil(1)*	6.355
4b	*LvMil(2)*	6.593
4c	*LvMil(3)*	7.498
4	***LvMil* ± SD**	**6.815 ± 0.603**
5a	*HmChi(1)*	6.431
5b	*HmChi(2)*	6.239
5c	*HmChi(3)*	6.293
5	***HmChi* ± SD**	**6.321 ± 0.099**
6a	*PkBcw(1)*	6.561
6b	*PkBcw(2)*	6.733
6c	*PkBcw(3)*	6.553
6	***PkBcw* ± SD**	**6.616 ± 0.102**

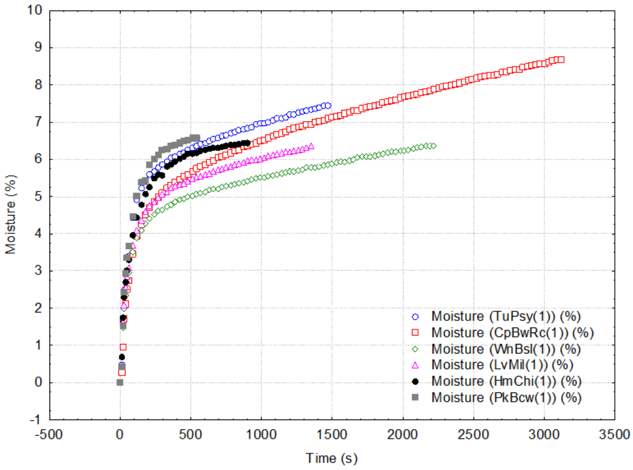

Figure 1. Moisture content (%) variation during the halogen drying process for the vegan cracker samples (triplicate (1))

3.2. Kinetics of the halogen drying process

The strength of retaining of water molecules into the food matrix can be qualitatively evaluated by means of kinetic curves of the drying process. Three pseudolinear variations of the actual moisture content, corresponding to different strength of water molecules retention, can be observed (Figure 1). Consequently, these types of retention of water molecules can be qualitatively compared between samples and the influence of various ingredients to the strength of water bonding (physical bonds) can also be evaluated.

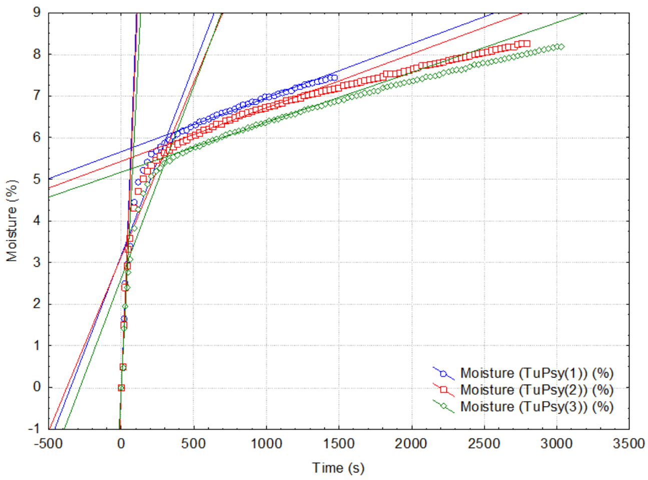

Figure 2. Variation of the actual moisture content (%) in time from the halogen drying of crackers with turmeric and psyllium (code *TuPsy*)

The correlational curves for the drying processes of cracker samples were obtained by linear regression for the pseudolinear variations of the actual moisture content during drying (Figures 2-7).

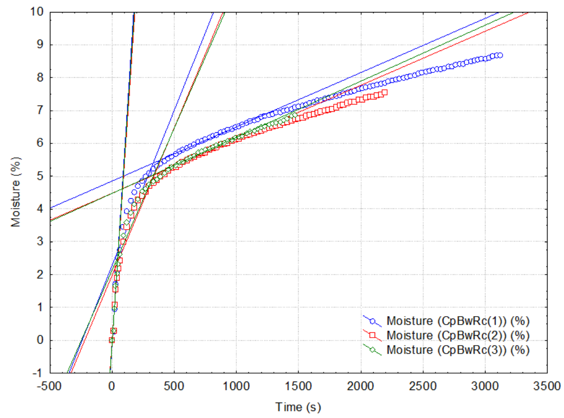

Figure 3. Variation of the actual moisture content (%) in time from the halogen drying of crackers with chickpeas, buckwheat and rice (code *CpBwRc*)

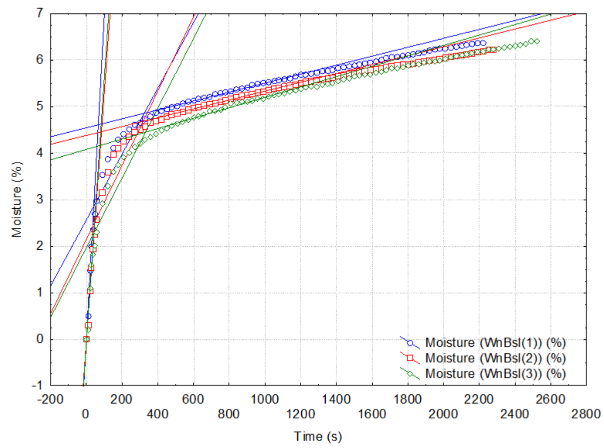

Figure 4. Variation of the actual moisture content (%) in time from the halogen drying of crackers with walnuts and basil (code *WnBsl*)

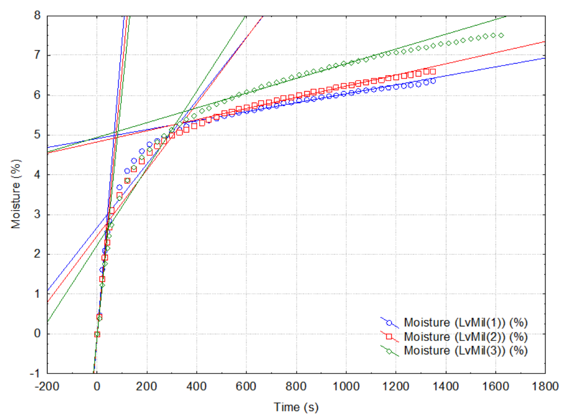

Figure 5. Variation of the actual moisture content (%) in time from the halogen drying of crackers with lavender and millet (code *LvMil*)

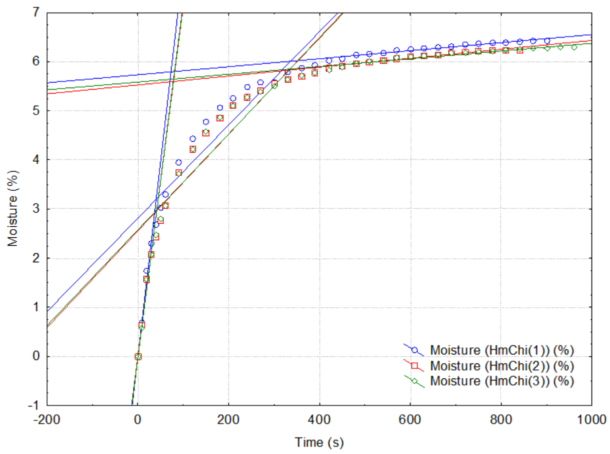

Figure 6. Variation of the actual moisture content (%) in time from the halogen drying of crackers with hemp and chia seeds (code *HmChi*)

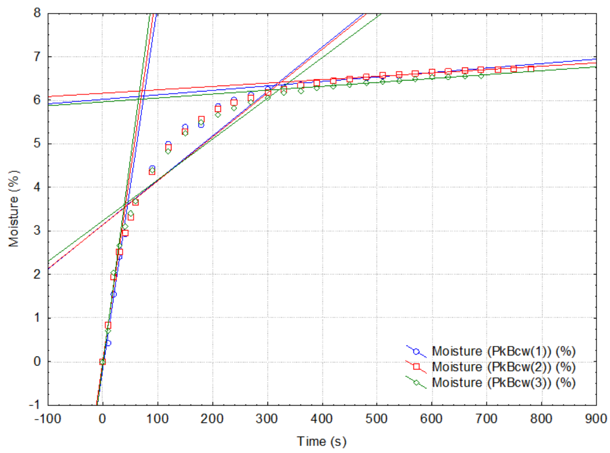

Figure 7. Variation of the actual moisture content (%) in time from the halogen drying of crackers with pumpkin and black caraway seeds (code *PkBcw*)

The variation of the moisture content was fast for the first time range (0-30 s), while this variation was much slower for the next two time ranges of 30-400 s and >400 s. However, the reproducibility of every triplicate analysis is very high (both for drying behavior and linear regression curves, Figures 2-7). The mass change during the first drying time range is attributed especially to the release of weak retained water molecules by the food matrix (i.e., by starch and gluten). These water molecules are also called "surface" water molecules and evaporate very fast. Consequently, the drying rates for such type of water were determined in the range of 0.057-0.088 %/s (Table 2).

Table 2. Halogen drying rates (%/s) corresponding to the release of "surface" water molecules (weak physically bonded into food matrix) for the first time range (0-30 s), determined for the cracker samples (data for triplicate analysis and mean values ± standard deviation)

Nº	Code	v_1 (%/s)
1a	*TuPsy(1)*	0.0866
1b	*TuPsy(2)*	0.0823
1c	*TuPsy(3)*	0.0676
1	***TuPsy* ± SD**	**0.0708 ± 0.0100**
2a	*CpBwRc(1)*	0.0582
2b	*CpBwRc(2)*	0.0548
2c	*CpBwRc(3)*	0.0564
2	***CpBwRc* ± SD**	**0.0565 ± 0.0017**
3a	*WnBsl(1)*	0.0693
3b	*WnBsl(2)*	0.0532
3c	*WnBsl(3)*	0.0568
3	***WnBsl* ± SD**	**0.0598 ± 0.0085**
4a	*LvMil(1)*	0.0742
4b	*LvMil(2)*	0.0670
4c	*LvMil(3)*	0.0615
4	***LvMil* ± SD**	**0.0676 ± 0.0064**
5a	*HmChi(1)*	0.0795
5b	*HmChi(2)*	0.0714
5c	*HmChi(3)*	0.0722
5	***HmChi* ± SD**	**0.0744 ± 0.0045**
6a	*PkBcw(1)*	0.0836
6b	*PkBcw(2)*	0.0866
6c	*PkBcw(3)*	0.0936
6	***PkBcw* ± SD**	**0.0879 ± 0.0051**

The lowest content of "surface" water was demonstrated by the lowest v_1 drying rate for the sample *CpBwRc*, 0.0565 (±0.0017) %/s (Table 2), which has a highest content of cereal flours (chickpeas, buckwheat and rice, which were specific ingredients for this sample). These ingredients strongly retain water molecules and the "surface" water will be less concentrated. On the other hand, cracker samples containing oily seeds such as pumpkin and black caraway based crackers, as well as hemp and chia seeds based confectionery products, have the highest "surface" water content, revealed by the highest drying rates for the first time range, 0.0879 (±0.0051) and 0.0744 (±0.0045) %/s, respectively (Table 2). It seems that the more hydrophobic content of *PkBcw* and *HmChi* samples allow water molecules to easily evaporate and the overall content of "surface" water will be higher.

In the second and the third drying time ranges the "strongly retained" water molecules are released.

Differences between v_2 and v_3 drying rate values have also been observed. Thus, the drying rates for the second time range was 0.0075-0.0099 %/s, with a lowest value for walnuts and basil based cracker samples of 0.0075 (±0.0005) %/s (Table 3). The third drying time range was the most relevant for the differences between samples, and further for the approximate content of "strongly retained" water molecules into the food matrices. The v_3 values vary in a wide range of 0.0008-0.0015 %/s and the observation related to the drying rate values on the first time range is sustained by the v_3 values. The highest v_1 values are inversely correlated with the lowest values for the v_3 drying rates. Consequently, the v_3 drying rates for the oily seeds based cracker samples are the lowest (0.0009 (±0.0001) and 0.0008 (±0.0001) %/s for *PkBcw* and *HmChi* samples, respectively, Table 3). The highest v_1 values were obtained for these samples. On the other hand, the highest v_3 value was obtained for the cereal based cracker samples (0.0017 (±0.0001) %/s, Table 3), which had the lowest values for v_1. These values are strongly correlated with the type of ingredients used for obtaining these fortified food products. Oily seeds based samples (especially *PkBcw* and *HmChi*) have higher content of "surface" water (weak bonded into the food matrix) and lower content of "strongly retained" water, while the cereal flour based crackers have the opposite situation, a lower content of "surface" water and a higher content of "strongly retained" water. Moreover, the drying time for oily seeds based cracker samples is much lower (540-780 s and 860-960 s) in comparison with the cereal based samples (1470-3120 s). This observation also sustain the above-mentioned affirmation related to the "surface" / "strongly retained" water (Figure 1).

4. Conclusions

In the present study, the moisture content and drying kinetics for various vegan crackers as functional food products have been evaluated using the halogen drying technique. A wide range of functional food samples have been selected from the main characteristics related to the quality and shelf life point of view. They contained ingredients with various characteristics that influence the way of water molecule bonding. Oily seeds or oily ingredients, spicy or aromatic plants having high content of essential oils, as well as different cereal flour types as cracker ingredients have been considered for the studied functional food products.

The moisture content of vegan crackers samples was in a narrow range of 6.3-8 %, under the limit established by national regulations for classical biscuits. Moreover, the kinetics of halogen drying process reveals valuable information related to the strength of physically bonding of water molecules into the food matrix. The oily seeds based crackers have a high content of "surface" water, while various cereal based vegan crackers provide a higher content of "strongly retained" water. These findings, including the ratio of drying rates corresponding to "surface" and "strongly retained" water contents, can provide in a short time and with reproducible results, valuable indices for the moisture content, water mobility and the strength of water bonding, as well as the quality of such types of fortified food samples.

Table 3. Halogen drying rates (%/s) corresponding to the release of "strongly retained" water molecules (strong physically bonded into food matrix) for the second and third time ranges (30-400 s and >400 s), determined for the cracker samples (data for triplicate analysis and mean values ± standard deviation)

Nº	Code	v_2 (%/s)	v_3 (%/s)
1a	*TuPsy(1)*	0.0091	0.0013
1b	*TuPsy(2)*	0.0084	0.0013
1c	*TuPsy(3)*	0.0092	0.0012
1	***TuPsy* ± SD**	**0.009 ± 0.0004**	**0.0012 ± 0.0001**
2a	*CpBwRc(1)*	0.0095	0.0017
2b	*CpBwRc(2)*	0.0090	0.0016
2c	*CpBwRc(3)*	0.0087	0.0017
2	***CpBwRc* ± SD**	**0.0091 ± 0.0004**	**0.0017 ± 0.0001**
3a	*WnBsl(1)*	0.0071	0.0010
3b	*WnBsl(2)*	0.0080	0.0010
3c	*WnBsl(3)*	0.0075	0.0011
3	***WnBsl* ± SD**	**0.0075 ± 0.0005**	**0.0010 ± 0.0001**
4a	*LvMil(1)*	0.0080	0.0011
4b	*LvMil(2)*	0.0083	0.0014
4c	*LvMil(3)*	0.0097	0.0019
4	***LvMil* ± SD**	**0.0087 ± 0.0009**	**0.0015 ± 0.0004**
5a	*HmChi(1)*	0.0095	0.0008
5b	*HmChi(2)*	0.0098	0.0009
5c	*HmChi(3)*	0.0098	0.0008
5	***HmChi* ± SD**	**0.0097 ± 0.0002**	**0.0008 ± 0.0001**
6a	*PkBcw(1)*	0.0102	0.0010
6b	*PkBcw(2)*	0.0101	0.0008
6c	*PkBcw(3)*	0.0094	0.0009
6	***PkBcw* ± SD**	**0.0099 ± 0.0004**	**0.0009 ± 0.0001**

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Compliance with Ethics Requirements. Authors declare that they respect the journal's ethics requirements. Authors declare that they have no conflict of interest and all procedures involving human and/or animal subjects (if exists) respect the specific regulations and standards.

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