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International Journal of Food Science and Technology - Manuscript ID IJFST-2018-25414

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KEY WORDS

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Journal:	*International Journal of Food Science and Technology*
Manuscript ID	IJFST-2018-25414
Manuscript Type:	Original Manuscript
Date Submitted by the Author:	12-Jul-2018

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Keywords:	Chips, Dietary Fibre, Co-product, Tiger-nut, Enrichment

Enrichment of chips with fibre from a tiger-nut (*Cyperus esculentus*) milk co-product to "*source of fibre*" and "*high fibre content*" levels: impact on processing, physicochemical and sensory properties.

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ABSTRACT

The impact of integrating a tiger-nut milk co-product into the wheat chip production process to enrich fibre content until the European reglamentation values "*source of fibre*" and "*high fibre content*" was studied. Four different flours, based on their composition and particle size, were obtained from the co-product. Wheat flour was substituted at the 5%, 10% and 20% levels with the co-product. Impact on processing, physicochemical and sensory properties of end product was studied. In the baking phase, mass loss was increase, but differences were equilibrated during tempering time. This effect was related to the increased chips surface during forming phase because dough viscoelasticity decreased. End chips presented significant differences in their physicochemical properties. Sensory evaluation was favorable for all formulas. The co-product as a fibre source produced alterations to chip processing that should be taken into account, however, chips did not have a negative impact on consumer acceptation.

Keywords: chips, fibre, co-product, tiger-nut, enrichment

1. INTRODUCTION

Incrementing dietary fibre intake is a recommendation made by Health Authorities because of the displacement of population dietetic habits to products with high-fat and refined carbohydrate contents (Dhingra, Michael, Rajput, & Patil, 2012) which, in turn, rises calorie input and poor nutrition. These dietetic habits have been catalogued as contributing to health diseases, such as type II diabetes mellitus, hypertension, obesity, and colon cancer (Dorner & Rieder, 2004; Retelny, Neuendorf, & Roth, 2008). Effects of increased fibre intake have been strongly related with physiological protection against coronary heart disease and other diseases as modification of blood lipid profiles (Wu et al., 2014).

Enriching the fibre content of food products with low-fibre content natively is an extended practice in industry (refined flours bakery, drinks, beverages, dairy and meat products) because it improves nutritional input, provides high-value products and contributes to competitiveness. These products should be labeling as "source of fibre foods" if contents 3g of fibre/100g of product and “high fibre content foods” 6g of fibre/100g of product. However, incorporation of fibre into pre-established matrix products induces changes across the process chain and sensorial properties, being many times non-viable enriching enough for labeling the denominations above mentioned. The most affected features are those related with physicochemical properties, such us rheological behaviour, heat conductivity, water retention, texture, colour, etc. (Bortnowska et al., 2016). Therefore, studying the impact of incorporating fibre sources into specific products, is a necessary experimentation area.

In this sense, there is a marked tendency in food industry of recovering from the secondary products valuable compounds contained in food processing waste, which represent in many cases a rich dietetic fibre source. These co-products can be converted into profitable products as raw materials for secondary processes (intermediate compounds), operating supplies, or ingredients of new products (Sánchez-Zapata et al., 2009). Along these lines, tiger-nut (Cyperus esculentus) milk co-product process is an excellent source of dietetic fibre, which is destined traditionally to organic mass for combustion, composting and feed production purposes. This false nut is the tuber of a Corsa sedge genus perennial herb member of the grass family Cyperaceae (Ayeh-Kumi et al., 2014). Interest in developing applications for this co-product also lies in the fact that large volumes of it are generated in several geographic zones of Spain (one of the world's main tiger-nut milk producers).

Data about the impact of this co-product on some food properties, such as pork sausages and burgers, have been reported in several studies (Sánchez-Zapata et al., 2010; Sánchez-Zapata et. al., 2013), but information about its effect on some food production chain phases of given products is still poor. One group of foods with more formulas including high-fibre content derives from cereal and bakery. Concretely, snack foods (related with high fat and salt contents) are less commonly produced enriched in fibre because of difficulties for obtaining acceptable products and processing impact. Hence the incorporation of fibre into snack food formulas can help improve their nutritional quality (Yuksel, Karaman, & Kayacier, 2014). This work was to study the viability of integrating a valuable high-fibre source like the tiger-nut milk co-product into chip processing until levels of "source of fibre" and "high fibre content".

2. MATERIAL AND METHODS

2.1 Raw materials: wheat flour and tiger-nut milk co-product conditioning

The tiger-nut milk co-product was obtained from a local tiger-nut milk manufacturing plant. It was presented as a coarse wet fibrous flour. Two types of triturated fibrous tissues were differenced from a macroscopic point of view in this co-product. The first had a particle size of approximately >800μm and was brown like any grain bran, and is provided by the periderm (skin) and cortex of the tuber. It is a typical woody fraction characterised by a high lignin content, among other insoluble polymers. The second had a particle size of some <800 μm and was quite white. It is provided by internal tuber parenchymal tissues, such as the perimedulla and medulla. It is a cottony material whose composition is based on insoluble carbohydrates, such as cellulose and hemicellulose (Habibi, Mahrouz, & Vignon, 2009). Since both are mixed perfectly at the end of tiger-nut milk processing, separation was done to allow the flour to be formed by an isolated white fraction, for which an 800-μm sieve was used. Thus two co-product flour types were obtained: total co-product (*T*) and white fraction (*W*). The decision was made to work with those two flour types to evaluate whether the white fraction reduces the impact on the colour attributes of the end product, which are among the most affected when enriching fibre content. Both flours were dried to 14% of moisture (w.b) to be remilled in a stainless steel grinder (Retsch GmbH, ZM 200, Haan, Germany) to obtain these two flour types, but in a small particle size version. The milled versions were called reduced particle of total co-product (Trp) and reduced particle of white fraction (Wrp).The commercial wheat flour that we used was obtained from a local producer (Molí del Picó-Harinas Segura S.L. Valencia, Spain). The alveographic parameters were also facilitated by the company, which were P=94±2 (maximum pressure (mm)), L=128±5 (extensibility (mm)), W=392±11 (strength (J-4)) and 0.73 of P/L. Particle sizes (Ps) of wheat flour and co-product flours are collected in Table S1. Proximate composition has also been included in Table S1, where fraction of protein, water, fat, ash and dietetic fiber are indicated. The particle size of the flours was measured 6 times by laser scattering in a Mastersizer 2000 (Malvern, Instruments, UK), equipped with a Scirocco dry powder unit. Proximate composition analysis were done by triplicated based on the ICC (International association for cereal science and technology) standards 110/1, 156, 136, 105/2 and 104/1 for water, dietary fibre, fat, protein and ash respectively.

2.2 Chips processing

The first chips production step involved mixing the wheat flour with the four co-product flours (T, W, Trp and Wrp). Three substitution levels applied: 5%, 10% and 20% w/w, all on dry basis (d.b). The percentages of substituted mass were calculated on the dry matter fraction of the used wheat flour to maintain the ratio of grams of water per gram of solutes constant between dough formulas (0.58g of water/g of solutes). These substitution levels were selected following the Regulation (EC) No 1924/2006 of the European Parliament and of the council of 20 December 2006 on nutrition and health claims made on foods. It indicates the parameters for “source of fibre foods”, which requires 3g of fibre/100g of product and “high fibre content foods” 6g of fibre/100g of product. In this sense, the 5% substituted formula is according with the first denomination; the 10% with the second one, and the 20% was included to evaluate the behavior and viability of a higher amount of fibre in the process. Thus, 13 different formulas were prepared (two flour types * two particle sizes * three substitution levels + the control). The formula of the control was: 65% wheat flour, 27.7% water, 5.7% oil (maximum acidity 0.2º Koipesol Semillas, S.L., Spain), 1.4% salt (refined marine salt ≥

97% NaCl Salinera Española S.A., Spain). These percentages remained constant for all the substituted formulas, and the amount of co-product flour varied according to each case. Twenty samples were produced for each formula. The procedure was as follows:

1. Liquid components (water and oil) and salt were placed into a food mixer (Thermomix® TM31, Vorwerk, Germany) and mixed to obtain a homogeneous solution (1.5min/50rpm).
2. The pre-homogenised mix of flour was added to the food mixer and mixed (4min/550rpm) with random turns of the mixer helix in both directions.
3. Homogeneous dough was allowed to rest in a sealed bowl for 20min at room temperature (20ºC).
4. The forming phase of the samples was carried out by separating 10-gram balls of dough to be placed in a manual laminator (IMPERIA SM/220, FIMAR, Italy) between rollers and maintaining a 2mm separation.
5. Baking was done in an oven (530x450x340, grill power 1200W, internal volume 32L, Rotisserie, DeLonghi, Italy) at 160ºC for 30min.
6. All the samples were allowed to rest for 10 minutes at room temperature.

2.3 Mass evolution in the baking phase

To collect mass loss data in the baking, the oven was coupled to a balance (K3R-15KD-SE, Gram Precision S.L., Barcelona) and weigh data were collected every 5min during the process. Finally, six weighing values were obtained with time, from which the mass loss kinetics were calculated in percentage terms based on Equation 1:

$$\Delta M_t = \frac{m_t - m_0}{m_0} \cdot 100 \quad (1)$$

Where ΔMt is the mass increment in % at any time, m_t the mass at any time and m_o the initial mass before baking.

2.4 Characterization of the end product: physicochemical and sensory properties

2.4.1 Mass loss and morphology properties

After tempering samples at room temperature for 10min, they were analysed in mass loss (ΔMf) and water fraction (Xw). Morphology of chips were evaluated based on the chips area (A). To evaluate the impact of the co-product flours on sample shape, areas of samples were obtained by scanning with scanner MICROTEK ScanMaker 9800XL Plus after baking and tempering. Images of samples were processed with the ImageJ image analyser software, where areas were calculated in pixels and converted into cm^2 by previous calibration. Impact in this phase is expressed as area increment in % (ΔA), between control formula and the rest of formulas.

2.4.2 Texture analysis

Texture of samples were evaluated analyzing the maximum braking force (H). The texture analysis procedure was based on Islas-Rubio et al. (2014). The breaking force in g of the chips was determined on texture analyzer TA-XT2 (Stable Microsystems, England) with a spherical-end accessory of 6.35mm in diameter at the test speed of 1mm/s. The hardness threshold was 1g and the distance threshold was 1mm. Twenty replies from each formula were analysed. Individual samples of each formula were placed on the fracture accessory (code TA-101) and the ball penetrated the chip until a complete fracture occurred. Breaking force (H) represents the maximum force required to break the chip.

2.4.3 Colour measurement

Colour measurements were taken after tempering samples. Hunter *L*, a, b* colour parameters were determined by a UV/VS Minolta Spectrophotometer model CM-3600d from 400 to 700 nm at 10-nm intervals using an integrating sphere. The employed colour system was CIE *L*ab*. Illuminant D-65 was used with 10° observer angles, which evaluates colour using typical bright daylight and an overcast sky and colour temperature at 6500K. The *L*, a* and *b* values were obtained from the mean of 10 determinations per formula. Whiteness Index (*WI*) was also calculated according to Bortnowska et al. (2016), the calculation equation was as follows:

$$WI = 100 - \sqrt{(100 - L)^2 + a^2 + b^2} \quad (3)$$

2.4.4 Sensory properties

In order to test the impact of the co-product presence in the product, a sensory assessment was made. The process was undertaken by 50 non-expert and untrained assessors, who are regular consumers of different types of chips. Tests were based on the semi-structured scales (AENOR, 2006) by which the attributes colour, odour, appearance, aftertaste, mouth texture and global acceptance were assessed. These attributes were selected as the most descriptive for both industry and consumers of such products. A questionnaire was used and was based on 8-cm lines where three reference points were represented (0 = unpleasant, 4 = acceptable, and 8 = pleasant) for each attribute. Each assessor evaluated two samples served at room temperature and coded them with a 3-digit random number. Samples were entire chips (Figure S1A).

2.5 Statistical procedure

A one-way and multifactor ANOVA was used to study the results of the dependent variables, as well as the main effects and interactions between factors (co-product flour type, particle size, substitution level, time). In cases with effect was significant (P-value < 0.05), the average was compared by Fisher's least significant difference (LSD). A multivariate unsupervised statistical method, Principal Component Analysis (PCA), was also used to report which variables better described each sample, and to therefore explain the differences between them simultaneously. PCA is a method used to describe and reduce the dimensionality of end product quantitative variables to a small number of new variables, called principal components (PCs), which are the result of the linear combinations of the original ones. The number of PCs was selected after considering the change in tendency on the screen plot, and also the accumulated percentage of explained variability above 75%.

3. RESULTS AND DISCUSSION

3.1 Mass evolution in the baking phase

Registered data of mass evolution during baking was represented in Figure 1 (until 30 min) in terms of percentage of mass increment (ΔM). Results showed the typical sigmoidal curves of heating, where a steep slope was produced until arriving to asymptotic zone, due to the reduction of water content in this case. All substituted formulas presented higher mass loss than control, although flour T presented the most one. The substitution level did not have effect, all curves appeared overlapping. Conversely, when baking time was finished and samples were tempered during 10 minutes, a recuperation of mass was observed (from 30 to 40 min, water mark zone

Figure 1). The mass increase during this time equilibrated the final mass loss (*ΔMf*) of all formulas until similar values. This effect has to be explained observing the differences in chips morphology. This parameter is deep discussed in the next section, however is necessary taking into account the differences observed in area of chips (*A*) (Figure S1). The increasing in the surface of chips when co-product flours were added produced an increment of migration front from the same dough weight, generating then a faster water loss during baking at the same time that a faster water recuperation from ambient during tempering time. Thus, in despite of the mass loss kinetics differences during baking, the mass loss differences were reduced between formulas across the tempering time.

3.2 Characterization of the end product: physicochemical and sensory properties

3.2.1 Mass loss and morphology properties

The results of final mass loss (*ΔMf*), water fraction (*Xw*) and area (*A*) are collected in Table 1. All cases presented significant reductions in the water fraction compared to control samples after tempering time, excepting samples with *Wrp*. Although these differences were significant statistically, the maximum of them was around 3% between control and *T* at 10%. This behavior was directly related with above discussed mass loss kinetics, assuming all mass loss as mass of water from dough.

In regard to the chips morphology, the effect of substitution resulted in incremented samples area processing under the same conditions, as has been commented above. The control presented an average area of 49.1±1.7cm^2, which was the minimum value of them all. The maximums were registered for non-milled co-product flours: *W* at 20%, with 86.9±1.1cm^2 and *T* at 20% with 76.9±0.7cm^2. All substituted formulas had statistically differences compared to control. Moreover, the two types of flours had not differences when were milled (*Wrp* and *Trp*) within each substitution level. For knowing the influence of each studied factor (substitution level, type of flour, particle size) in the total variance, the results were analyzed by a multiple ANOVA, and then the significance of the main effects for the factors substitution level, particle size and co-product flour type were determined. Significance for the main effect of the substitution level and particle size was observed, following that same order of importance based on their F-ratio. Moreover, co-product flour type had no significant main effect on dough behavior in this variable. A significant interaction was also observed between substitution level-particle size, and substitution level-type of flour. Therefore, the type of flour had significance in non-milled flours, since it appeared to have the same behavior when particle size was reduced.

Results showed an affectation of the rheological properties of doughs that makes influence on forming phase of product. This effect was principally done because the amount of gluten available to generate the gluten matrix was smaller, which reduced dough retraction capacity after formation. Presence of different solids, such as insoluble fibre, also disrupted optimal gluten network formation, and led to alterations in dough behaviour (Tuhumury, Small, & Day, 2016). This weakening of wheat doughs because replacements with bran and rich-fibre compounds is a typical phenomenon (Sudha, Vetrimani, & Leelavathi, 2007)

Figure S1B shows the incremented area of samples in all cases compared to the control. The co-product with the original particle size presented a greater increment of area, while the reduced particle size flours had less impact on gluten matrix formation, despite having been incorporated at the same substitution level. The morphology was significantly impacted.

3.2.2 Texture analysis

Hardness of chips (*H*) presented regular reduction with substitution level. In both cases, co-product flours with reduced particles (Wrp and Trp) presented lesser reduction than the original size ones (*W* and *T*). Between *W* and *T*, the first one presented the maximum impact on this variable, generating the softest chips. These results followed the causes described previously on morphology changes and are in the same line as reported studies about effect of cellulose and other fibres in wheat flour substitutions. In this sense, the effect of different cellulose fibres was the reduction in energy required to tear wheat flour doughs from 5% (Goldstein, Ashrafi, & Seetharaman, 2010). Concretely, reductions around 10 and 20% in energy required to tear of pure wheat gel samples were described in substitutions of 5 and 10% respectively. In our case, the hardness reduction ranges were from 5 to 20%: 5-55% for *W*, 12-37% for *Wrp*, 2-33% for *T* and 1.5-18% for *Trp* repectively. The disruption of correct starch-protein formation is equally interpretable; however, the vitreous matrix of chips generates harder differences between substitution levels than viscoelastic systems like gels.

Thus, if these disruptions were produced because the presence of non-wheat flour materials, they should be related with the particle size. Therefore, the effect of particle size should be related with the hardness, but also with area (*A*), since differences in this morphological parameter produces differences matrix configuration of samples. To explore this fact, a plot was made with hardness (*H*), chip area (*A*) and average of particle size (*Ps: D [4. 3]*), Figure 2. Four different models were observed in function of type of co-product flour, having beginning on control. In all cases, H presented inversed relationship with *A* and *Ps*, having higher slope for *W* and *T* flours. The differences in models direction within space revealed the effect of specific flour type, where both *W* and *Wrp* presented less *H* in chips with similar *A* and *Ps*.

3.2.3 Colour measurement

The colour parameters presented clear differences when particle size were modiffied in the same co-product flour. *L** was mostly reduced in samples with *Wrp* and *Trp.* In all them, both parameters *a* and *b* increased, which agreed with displacement of colour towards brown tonalities between yellow and red. The colour difference (ΔE) presented higher values for *T* and *Trp*, which agreed with the fact that those flours maintained the original fibre covering from external tiger-nut parts, which is brown as any grain bran is. Regarding the Whiteness Index (*WI*), the control presented the highest *WI* value. The minimum ones were the samples with both reduced particle flours (*Trp* and *Wrp*). When testing the relationship between *WI* and % of substitution (Figure 3) we observe the tendency formed between them, where the increment in % also meant a drop in the *WI* values, except for the *W* samples. Note that the same increments in the substitution level greatly reduced *T* and increased *W*; indeed, *W* was the most similar to the control when substitution rose. An increase in *W* could compensate the effect of light scattering due to surface rugosity, and also due to recovered lightness and whiteness (Chung, Degner, & McClements, 2013). Moreover, reduced particle size produced a similar response for both flours, an accentuated reduction in whiteness, and irrespectively of flour type. So flour *W* presented a higher margin for substitution level and had a less color impact on all the co-product flour types.

3.2.4 Sensory properties

The results of scores and analysis of variance for sensory analysis were collected in Table S2. All scores for all variables exceeded the category “acceptable” (>4), therefore the captured variability was linked to products that were considered suitable for consuming according to the panel of untrained assessors. Some formulas reached scores with no differences to control (marked in cursive letter). Flours *T* and *Trp* got the most of this cases, principally in global acceptance, odour, appearance and taste. In *W* and *Wrp*, this last one presented the most scores in common in regard to odour and taste. *T* and *Trp*, in despite of a higher particle size and visual impact, appeared to offer better sensory properties than the isolated white fraction.

With the aim of evaluate the relationships between sensory results and physicochemical properties, a correlation study was carried out and a significance map was generated (Table S3). There were correlations with high significance ($\alpha=0.05$, $\alpha=0.025$ and $\alpha=0.01$) between several variables from the data blocks. Were highlighted the case of color, which was inversely related with *A*, ΔMf and *Ps* in *W* and *Wrp* flours, however global appreciation indicated positive relationship with *WI* and L*, which reveals the effect of whiteness when particle was reduced on *Wrp* flour. Color was also inversely with *a* and *b* of flour *T*, probably because the excessive visualization of co-product particles along chip surface (Figure S1). This relationship was according to appearance results, which was commonly correlated with *Ps* negatively. Ps was also related negatively with texture and global appreciation in *T*. Those results centered *Ps* as the main factor or sensory depletion for *T*.

4. CONCLUSIONS

The impact of adding the tiger-nut milk co-product was significant both on chip production and end product. Reduced wheat from substitution level and gluten network disruption by fibre particles caused the reduction of viscoelastic capacity of dough. This effect generated chips with a larger surface, which increased the mass loss during baking, although it was compensated along tempering time, reducing the differences among formulas. The physicochemical properties of the resulting products presented significant differences, which were highly related with type of co-product flour and substitution level, which reveals the co-product's particle size importance. The mean impact was observed on reduced hardness and color properties. Sensory properties raised acceptable values for all formulas and some of them without differences to pure wheat chips. White fraction did not produce any advantage about consumer perception. Therefore, the inclusion of co-product as fibre source generated alterations to chip processing that should be taken into account to optimise operations, however it did not have necessary negative impact on sensory acceptation, which makes plausible to obtain chips cataloged as "source of fibre" and "high fibre content".

ACKNOWLEDGEMENTS

This study was supported by Regional Valencian Ministry of Culture, Education and Sport for Scientific and Technological Politics by Project entitled "*Use of non-wheat flours, from co-products of the food industry, to produce bread, cakes and snacks* (AICO/2015/107)"

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FIGURE 1

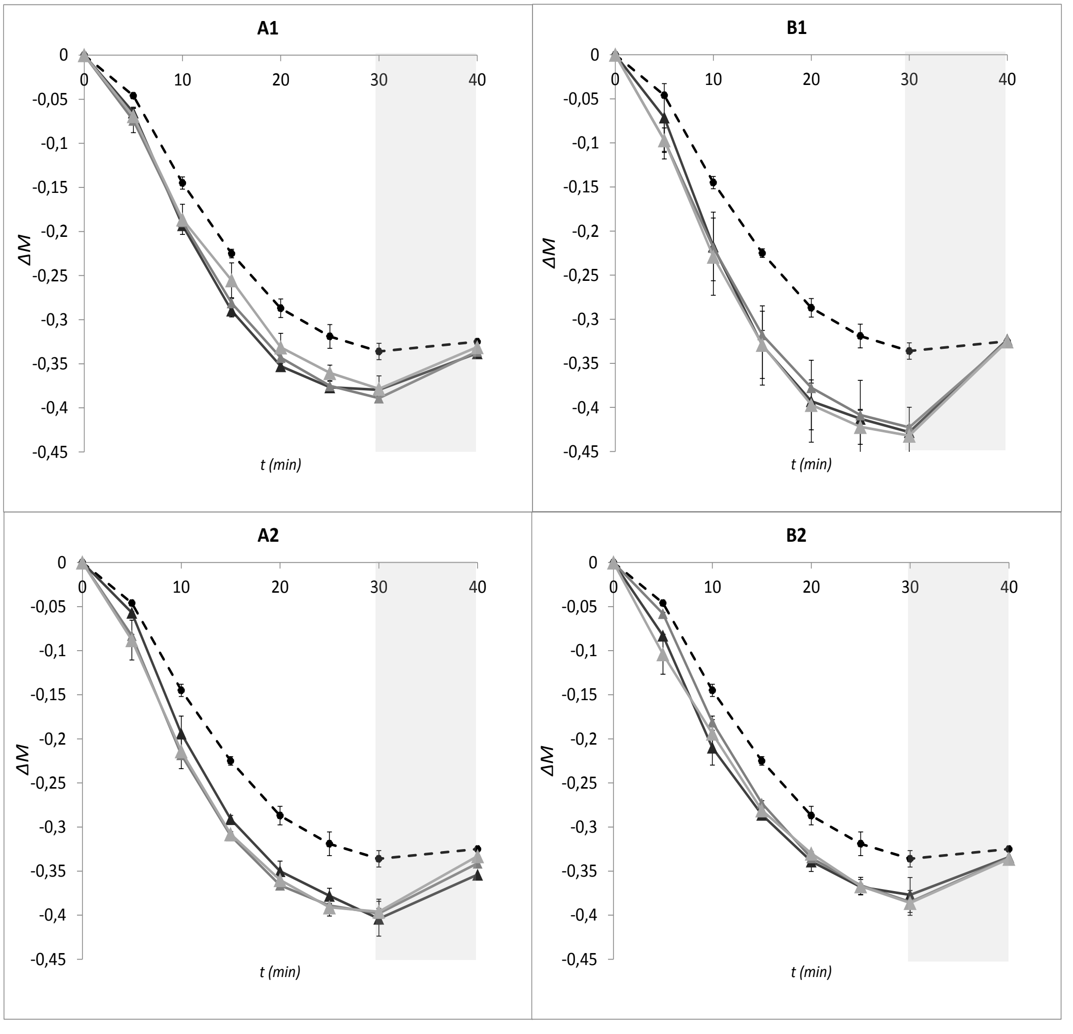

FIGURE 2

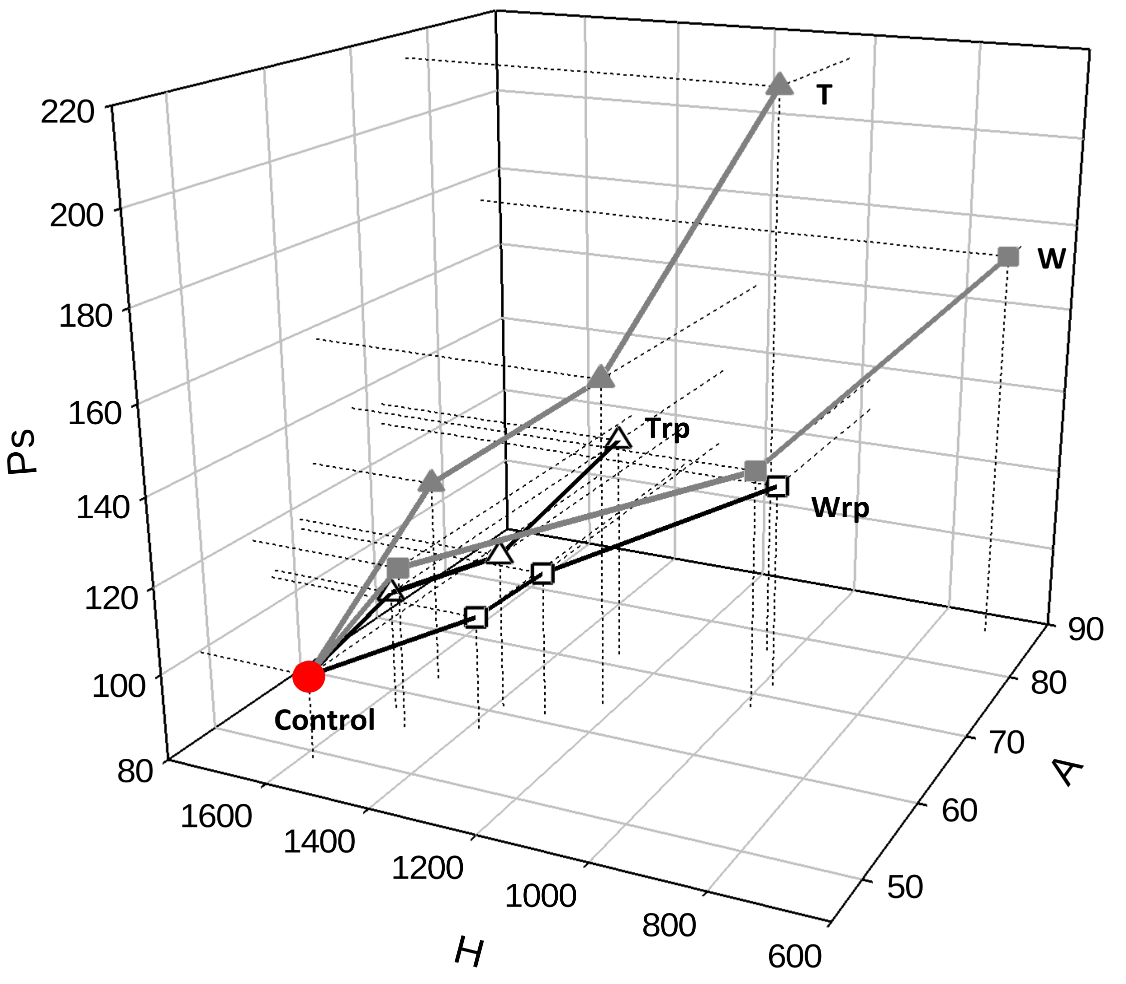
T
W
Trp
Wrp
Control
Ps
220
200
180
160
140
120
100
80
1600
1400
1200
1000
800
600
H
90
80
70
60
50
A

FIGURE 3

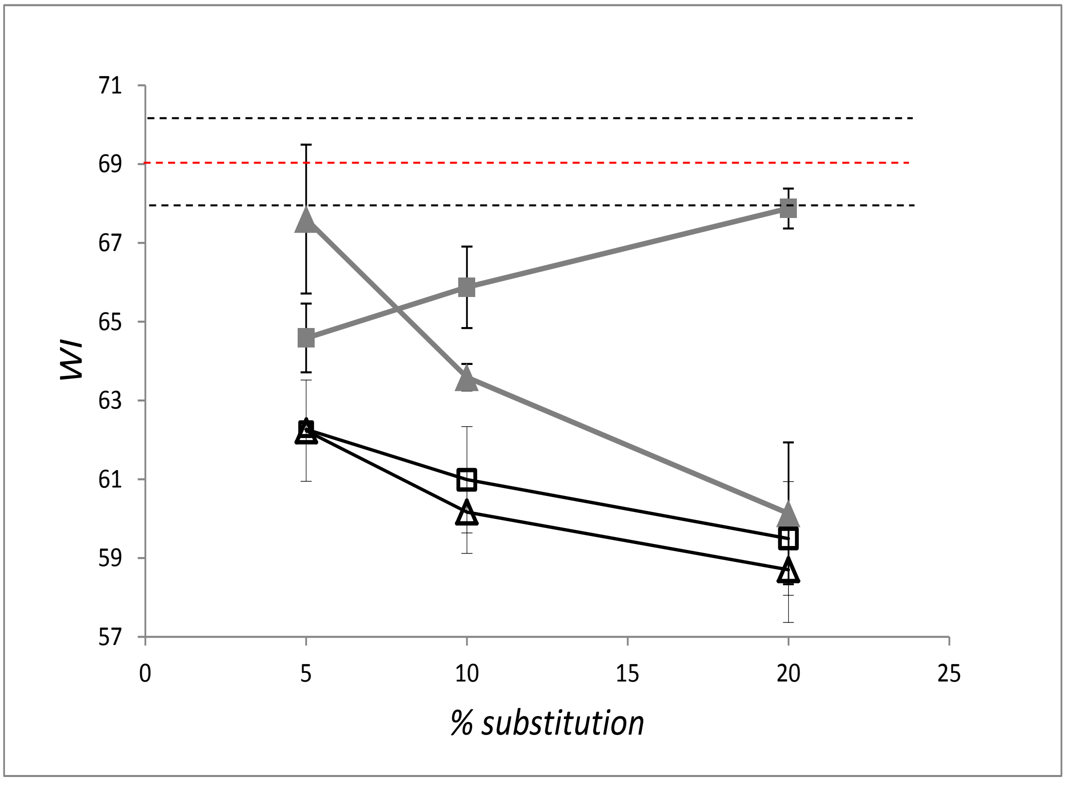

Table 1. Results of the physicochemical properties of chips.

Flour type	*%*	*Ps*	*A*	*ΔMf*	*Xwf*	*H*	*L**	*a*	*b*	*ΔE*
Control	0	99.4±5.6	240±8.6a	32.5±1a	0.15±0.01b	1581±68c	73.4±0.9e	1.4±0.1a	15.8±0.7a	-
W	5	117.9±4.9	270.7±8.4b	33.1±1.3b	0.14±0.01a	1601±81b	70.1±0.7d	2.9±0.2b	18.7±0.9b	4.7±1.3a
	10	136.5±3.8	332.1±5.2d	33.6±1.3b	0.14±0.01a	983±71b	71.8±0.6d	3±0.2b	19±0.9b	3.9±1.4b
	20	173.6±6.2	424.1±5.5f	33.8±0.9b	0.13±0.01a	701±35a	73.3±1.3e	2.7±0.3b	17.6±0.6b	2.2±1b
Wrp	5	106.7±5.3	279.9±3.6b	33.3±0.7b	0.15±0.01b	981±53b	68±1.2c	3.6±0.2c	19.6±0.8bc	7±0.8bc
	10	114.1±4.9	298±11.7c	35.1±0.8b	0.16±0.01b	1302±37b	67.4±1.3bc	4±0.3c	21.1±0.8c	8.4±1cd
	20	128.8±4.6	350.2±11.5e	33.4±1b	0.15±0.01b	1380±39a	65.8±0.8b	4.4±0.2c	21.3±0.7c	9.8±0.5cd
T	5	128.1±6.1	307±14.1cd	32.5±0.9ab	0.14±0.01b	1650±38c	76.5±1.6e	1.9±0.4a	22.1±1.6c	7±1.2b
	10	156.8±4.8	313±6.2d	32±1.6a	0.12±0.01ba	1228±39b	73.1±5.1e	4.1±1.6d	24±2.1d	8.6±1c
	20	214.2±7.2	375.6±3.87f	32.3±0.8a	0.14±0.01ba	1050±44ab	71.8±1.3e	5.3±0.9e	27.7±2.3e	12.6±1.3d
Trp	5	107.9±4.2	281.7±11.5b	33.6±0.8b	0.14±0.01a	1556±52c	66.9±1.4bc	3.2±0.2c	18±0.5b	7±1.8bc
	10	116.5±4.2	297.6±12.5c	34±0.5b	0.13±0.01a	1385±46b	65.5±1.1b	4±0.3d	19.5±0.5b	9.1±0.3cd
	20	133.7±5.1	350.7±8.6e	33.4±0.5b	0.14±0.01a	1295±63b	63.1±1.2a	4.3±0.3d	18±0.8b	10.9±1.8cd

FIGURE S1

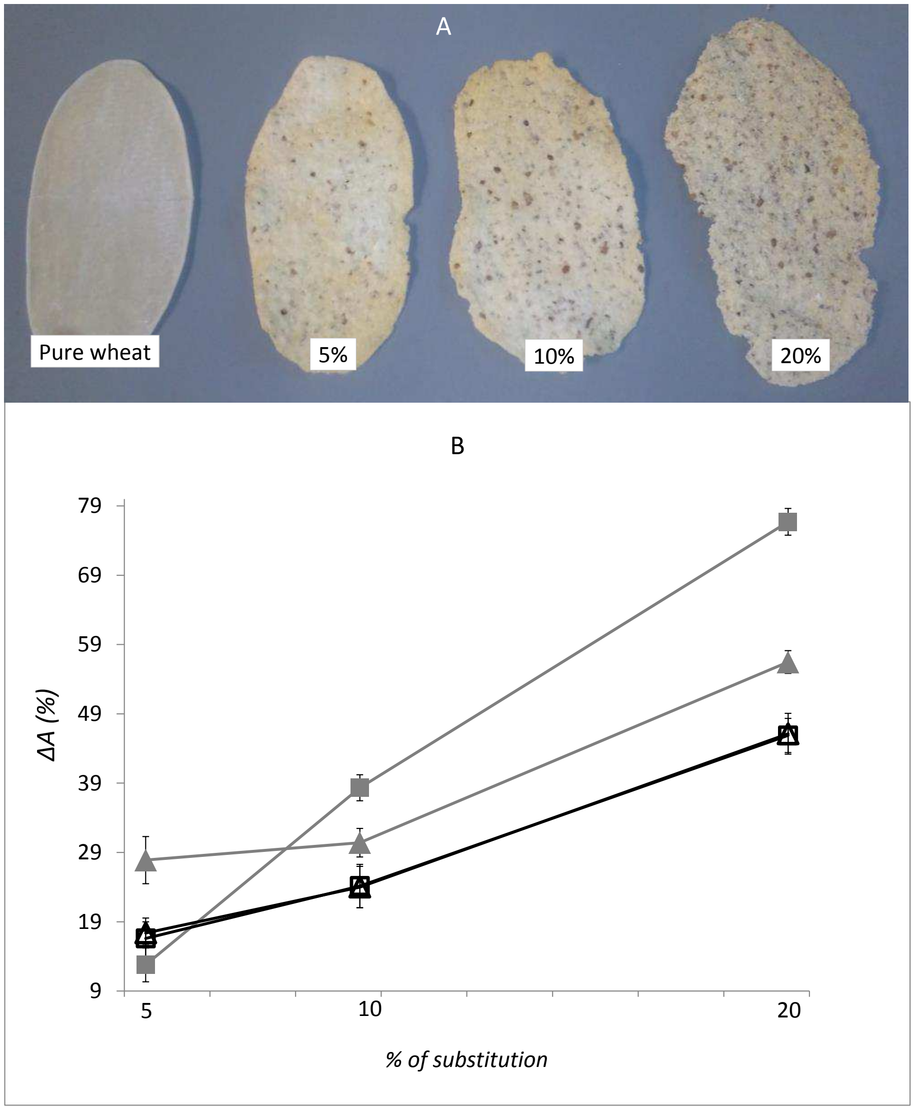

Figure S1. Chips dough with co-product. A: image of the example chips formulated with *T* flour at the 0%, 5%, 10% and 20% levels of substitution (d.b). B: Increment of the chips area after the forming phase *vs.* % of substitution. Filled square: *W* flour; Empty square: *Wrp* flour; Filled triangle: *T* flour; Empty triangle: *Trp*. ΔA: incremented surface compared to the control (%). Bars mark standard deviations.

Table S1. Characterization of tiger-nut milk co-product and wheat flour.

Flour type	***Particle size***				***Proximate composition***				
	d(0.1)	***d(0.5)***	***d(0.9)***	***D [4. 3]***	X_p	X_f	X_w	X_a	X_{df}
Wheat	25.5±1.1	92±0.6	180.6±0.8	99.4±1.2	0.147±0.06	0.01±0.001	0.14±0.005	0.003±0	0.002±0
T	166.2±26	587±51	1326±33.6	673±38.8	0.019±0.007	0.09±0.001	0.14±0.004	0.018±0.001	0.69±0.004
Trp	24.3±0.7	182.7±7.7	663.6±32.4	271.1±14.5					
W	225.5±4.5	433±8.2	777.9±14.7	470.4±9.1	0.015±0.007	0.078±0.001	0.14±0.004	0.015±0.001	0.71±0.003
Wrp	31.9±0.7	197.4±7.7	516.5±32.4	246.7±14.5					

W: white fraction flour; *Wrp*: white fraction flour with reduced particle, *T*: total co-product; *Trp*: total co-product with reduced particle; *Xp*: protein fraction; *Xf*: fat fraction,;*Xw*: water fraction; *Xa*: ash fraction; *Xdf*: dietary fibre fraction. Letters within columns mean significant differences at ≤ 0.05. Particle size (*Ps*) has been expressed in volumetric fractions (maximum size (μm) at 10% (d (0.1)), 50% (d (0.5)) and 90% (d (0.9)) as their averages (D [4, 3]) of the total volume of the analyzed particles.

Table S2. Results of the sensory properties of chips.

Flour type	*%*	*Color*	*Odour*	*Appearance*	*Taste*	*Texture*	*Global*
Control	0	***6.2±1.1f***	***5.5±0.9cd***	***6.1±1.1e***	***5.4 ±1.5d***	***7.5 ± 0.3f***	***6.1±1.6d***
W	5	5.5 ±1.2cd	5.1±0.9b	5.5± 1.0d	4.3±1.1ab	6.0±1.8b	5.5±0.9bc
	10	4.9±1.3b	4.8±0.7a	5.1±1.1bc	***5.2±1.1cd***	6.2±1.4bc	5.0±0.6ab
	20	4.7±1b	4.7±1.1a	4.5±1.4a	4.1±1.2a	4.8±1.9a	4.8±1.0a
Wrp	5	5.3±1.1c	***5.2±1.0bc***	5.4±0.9d	4.9±1.0c	6.6±0.3cd	5.5±1.1bc
	10	5.5±0.9cd	***5.5±1.0 cd***	5.4±0.9cd	***5.5±1.3d***	6.4±0.8c	5.7±0.9c
	20	4.3±1.5a	4.7±1.0a	4.2±1.4a	***5.2±1.2cd***	6.4±1.0c	5.2±1.0b
T	5	5.9±0.9e	***6.0±1.2f***	***6.1±1.0e***	***5.7±1.2d***	6.9±0.8d	***5.8±0.9cd***
	10	5.6±0.9cd	***5.4±0.8cd***	***6.0±0.6e***	***5.3±1.5cd***	6.8±0.9d	***5.8±1.1cd***
	20	5.6±1.1cd	***5.5±1.3cd***	4.9±1.5b	4.5±1.5b	5.8±0.9b	4.8±1.1a
Trp	5	***6.1±0.7ef***	***5.5±0.9de***	***5.8±1.1e***	5.0±1.2c	6.9 ±0.6d	4.9±0.9a
	10	5.4±1.2d	***6.3±0.6 g***	***5.8±1.2e***	***5.5±1.6d***	7.2 ±0.4e	***5.8±1.2cd***
	20	5.2±1.3c	***5.8±0.9ef***	5.5±1.4d	***5.3±1.4cd***	6.8 ±0.6d	***5.7±1.2cd***

W: white fraction flour; *Wrp*: white fraction flour with reduced particle, *T*: total co-product; *Trp*: total co-product with reduced particle. Letters within columns mean significant differences at ≤ 0.05.

Table S3. Correlation map between physicochemical and sensory properties.

A1	color	odour	appearance	taste	texture	global
A	-		-			
ΔMf	-	-	-			
Xwf	+		+		+	
H	+	+	+			
Ps	-		-			
ΔE						
Wi						
*L**						
a						
b						

B1	color	odour	appearance	taste	texture	global
A					-	-
ΔMf			+	+		+
Xwf	+				+	
H						
Ps			-		-	-
ΔE	-				-	
Wi					+	+
*L**		+				
a	-					
b	-				-	

A2	color	odour	appearance	taste	texture	global
A	-		-			
ΔMf	-		-			
Xwf						
H						
Ps	-		-			
ΔE					-	-
Wi					+	+
*L**					+	+
a					-	-
b					-	

B2	color	odour	appearance	taste	texture	global
A	-		-			
ΔMf						
Xwf						
H	+					
Ps			-			
ΔE						
Wi						
*L**			+			
a						
b						

W: white fraction flour; *Wrp*: white fraction flour with reduced particle, *T*: total co-product; *Trp*: total co-product with reduced particle; *Ps*: average particle size of mixed flours [D 4.3]; *A*: surface of chips in cm^2; Δ*Mf*: mass increment at end of tempering time in %; *Xwf*: water fraction at end of tempering time; *H*: maximum force (g); *L**, *a* and *b*; CIE Lab space colour parameters; Δ*E*; colour difference. Colours indicates the signification level α: 0.05 ░ 0.025 ▒ 0.01 █. Symbols indicate positive or negative correlation.