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TEXTURAL CHARACTERISTICS OF TYPICAL ITALIAN "GRISSINO STIRATO" AND "RUBATÀ" BREAD-STICKS

CARATTERISTICHE STRUTTURALI DEI GRISSINI TIPICI ITALIANI "GRISSINO STIRATO" E "RUBATÀ"

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ABSTRACT

Stretched ("Grissino stirato") and rolled ("Rubatà") bread-sticks are typical Italian bakery products that are also widely produced in other EU countries. Despite their wide distribution there are no studies available on these products. Therefore, the aim of this study was to distinguish them according to their chemical composition and textural characteristics determined by a compression test using a Texture Analyser. Fifty samples (25 of each kind of bread-stick), produced by different

RIASSUNTO

Il "Grissino stirato" ed il "Rubatà" sono grissini tipici italiani ampiamente prodotti però anche in altri Paesi europei, ma sui quali non sono mai stati svolti studi o ricerche. Lo scopo di questo lavoro è stato quindi quello di caratterizzare dal punto di vista compositivo, ma soprattutto strutturale questi prodotti. La ricerca ha interessato 50 campioni (25 per ciascuna tipologia) e le misure di texture sono state eseguite mediante un Texture Analyser in modalità di compressione. I dati raccolti

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bakers, were examined. Variance analysis showed that the two bread-sticks only differed with respect to texture parameters. There were no differences in chemical parameters. The higher values of the maximum force and of the average puncturing force indicate that the rolled "Rubatà" bread-stick has a firmer character than the stretched "Grissino stirato" bread-stick. On the contrary, the number of spatial ruptures and the ruggedness index were higher for the stretched "Grissino stirato" bread-stick. For product authentication an Artificial Neural Networks (ANN) with a three-layer, fully interconnected, feed-forward architecture was used. ANN is an effective and powerful tool for distinguishing these products with a very high average learning (94% for rolled bread-stick and 93% for the stretched bread-stick). The model obtained can be easily used for product authentication.

sono stati elaborati mediante l'analisi della varianza ed i campioni sono stati discriminati mediante una Rete Neurale Artificiale a tre livelli con connessioni complete. I maggiori valori di forza di rottura sono stati riscontrati per il grissino "Rubatà" mentre il numero di rotture nell'unità di spazio e l'indice adimensionale di frastagliatura sono risultati maggiori per il "Grissino stirato". La Rete Neurale ha confermato queste differenze evidenziando una capacità di riconoscimento del 94% per il grissino "Rubatà" e del 93% per il "Grissino stirato". Il modello così costruito potrà essere vantaggiosamente utilizzato dagli Organi di Controllo per la definizione dell'origine del prodotto.

INTRODUCTION

Traditional bakery products such as "pizza" from Naples, "panettone" from Milan, "pandoro" from Verona and "bread-sticks" from Turin-Piedmont have a ubiquitous presence on the Italian food market. Some of these items, like pizza and panettone, have been become important symbols of Italian cuisine worldwide. Bread-sticks are also well known and appreciated and rank high among Italian food exports. Bread-sticks are native to the Piedmont region (north-western Italy), where they have been produced since 1600. There are currently two commercial types, "Grissino stirato" and "Rubatà" on the market (SCARLINO and MAINA, 1989). The production technology and raw materials are well-established and the products are very similar. There are no noticeable differences between the two types with respect to chemical composition or appearance but they differ in production technologies and they differ in structure (QUAGLIA, 1984; BARBERIS, 2000) and commercial price. Bread-sticks are crispy products and it is crispness that appears to be the single most versatile characteristic that has determined their success and is also the factor that distinguishes one from the other. Even if crispness has not yet been satisfactorily defined, it is agreed that it is a textural characteristic that has many positive connotations.

Until the 1960s crispness was defined as the quality of fracturing into many small pieces under compressive pressure. It is associated with brittleness. Later, progress was made in optimising testing methods and refining the vocabulary of crispness, though interchangeable terms describing the texture status are still in use. Most published studies investigating the importance of different sensory perceptions on consumer acceptability conclude that texture, flavour and appearance are the most important sensory modalities (VALLES PAMIES *et al.*, 2000; GÁMBARO *et al.*, 2002; SCHER and HARDY, 2002; BOOTH *et al.*, 2003; KARADZHOV and ISERLIYSKA, 2003; MEULLENET *et al.*, 2003).

In addition to its direct contribution to consumer acceptance, texture has important secondary effects, through modulation of flavour release and its influence on appearance. Texture and food structure are inextricably linked: the micro- and macro-structural composition of foods will determine sensory perception and any change in the structure carries the risk of changing perceived texture and violating consumer expectation.

Based on recently published literature (BASMAN and KÖKSEL, 1999; PIAZZA *et al.*, 2001; BOURNE, 2002; CROWLEY *et al.*, 2002; MURRAY *et al.*, 2002; ZEPPA *et al.*, 2002; RAFFO *et al.*, 2003; SHOGREN *et al.*, 2003; DEMIREKLER *et al.*, 2004; PASQUALONE *et al.*, 2004) the aim of this study was to define the textural characteristics of the two commercial types of typical Italian bread-sticks “Grissino stirato“ and “Rubatà” and to develop a model for distinguishing them by using the Artificial Neural Networks (ANNs) approach. As their product aspect is similar they can be easily mistaken by consumers but the “Rubatà” bread-stick purchase price is higher than that of “Grissino stirato” bread-stick. So a technique to distinguish them is very important for product authentication and consumer safeguard. Among the mathematical techniques for prediction, classification or control, the Neural networks provide a powerful tool for characterising, distinguishing and authenticating food products.

ANNs is an information processing paradigm that is inspired by the way biological nervous systems process information and they have more recently been applied in many scientific fields: physics, medicine, botany and food science (BOS *et al.*, 1992; DAWN, 1994; VALLEJO-CORDOBA *et al.*, 1995; HORIMOTO *et al.*, 1997; GERBI *et al.*, 1998; NI and GUNASEKARAN, 1998; MANCUSO *et al.*, 1998; CICCHELLI *et al.*, 2000; MITTAL and ZHANG, 2000; BALESTRIERI *et al.*, 2001). An ANN is a computational system which processes numerical input (training data) through a learning process and converts it into a final output. It is typically organised into “layers” which are made up of a number of interconnected “nodes”. The data (in this case the texture values) are usually transferred to ANN via the “input layer” and with a system of “transfer functions” and “node weights”. These weights correspond to synaptic efficacy in a biological neuron. Each neuron also has a single threshold value. When the weighted sum of the inputs is formed the threshold is subtracted to compose the activation of the neuron. This activation signal is passed through an activation function and the network computes a response at the output layer. These values are then compared to the actual values of the response variable (in this case the bread-stick classifications) and an error is computed. With a back-propagation algorithm this error is used to adjust the “node weights” and the network computes a new response. The iterative procedure of processing inputs, determining the errors and adjusting the weights is the “learning process”. Iteration continues until the network response errors are kept to a minimum. Very important in this architecture is the weight of input neurons that are changed by an amount proportional to the difference between the desired output and the actual output and are a proportional index of importance of these input neurons for product classification.

Neural networks, with their remarkable ability to derive meaning from complicate or imprecise data, can be used to extract patterns and detect trends that are too complex to be noticed by either humans or other computer techniques. Unlike other mathematical systems, such as Discriminant Analysis or Cluster Analysis, for the classification of different samples, the mathematical model developed in the ANNs can be used independently from the value used for its construction and subsequently applied to product control. In this work ANNs were then applied to the textural characteristics of "Rubatà" and "Grissino stirato" bread-sticks to define a mathematical model that can be used for product characterisation and authentication and consequently for market control.

MATERIALS AND METHODS

Samples

Bread-sticks were produced by fifty Piedmont (north-western Italy) bakers: twenty-five produce stretched bread-sticks or "Grissino stirato" and the other twenty-five produce rolled bread-sticks or "Rubatà".

Two production batches were examined for each baker and a sample of 1 kg of bread-sticks was collected for each production batch.

In the stretched "Grissino stirato" bread-stick technology, flour (type 00), water (40-60%), yeast (0.5-4%), pork fat (0.8-8%), olive oil (0.6-7%), salt (1.3-2.5%) and malt (0.5-3%) are typically used. Ingredients are mixed (about 20 min) and then the dough is divided into small portions. After the fermentation step (about 1 h), cylindrical strips are hand-rolled into bread-sticks. These cylinders are gently lengthened by hand-stretching to about 100 cm. Baking follows at 205°-300°C for 10-30 min. The attribute "stretched" ("stirato") is therefore really due to this unique hand stretching mode that serves to give the dough the peculiar elongated properties characteristic of the final baked structure.

In the rolled "Rubatà" bread-stick technology, flour (type 00), water (50-60%), yeast (0.1-2.6%), pork fat (2-7%), salt (0.8-2.5%) and malt (2-4%) are used. Ingredients are mixed (about 20 min) and then the dough is divided into small portions. After the fermentation step (about 1 h), the dough is formed into cylindrical strips from which the bread-sticks are made. These cylinders are gently rolled by hand to about 50 cm length and then baked at 190°-270°C for 5-20 min. Shaping dough by means of a rolling action promotes relevant biaxial extension stresses in the structure and the consequent viscoelastic properties differ from those of the stretched bread-stick dough where only elongational stress induced in the shaping technology results in more elastic attributes. The rolled "Rubatà" bread-stick can be compared to a special elongated baked crumble bread.

Chemical analysis

Chemical analyses were performed immediately after each production. Bread-stick moisture, ash and protein (nitrogenx5.7) contents were determined according to the AACC methods 44-15A, 08-01 and 46-11A, respectively (AACC, 2000). Fat and starch were determined according to an official Italian method (ITALIAN GOVERNMENT, 1994). Glucose, fructose, lactose and maltose were determined according to ZEPPA *et al.* (2001) with an HPLC system (Thermo Electron Corporation, Waltham, MA, USA) equipped with an isocratic pump (P1000), a multiple autosampler (AS3000) fitted with a 20 μL loop and a refractive index RI-150 detector. Data were collected on a EZChrom ver. 6.6

system (Thermo Electron Corporation, Waltham, MA, USA).

The analyses were performed isocratically at 1 mL/min and 65°C with a 300x7.8 mm i.d. ion exclusion column Aminex HPX-87H equipped with a Cation H^+ Microguard cartridge (Bio-Rad Laboratories, Hercules, CA, USA). The mobile phase was 0.013 N H_2SO_4 prepared by diluting reagent grade sulphuric acid with distilled water, filtered through a 0.20 μm membrane filter (Sartorius AG, Göttingen, Germany) and degassed under vacuum. Five grams of bread-stick were added to 25 mL of 0.013 N H_2SO_4 (mobile phase), the resulting suspension was then extracted for 10 min with a Stomacher (PBI, Milan, Italy). The use of a Stomacher laboratory blender allowed a time reduction because the extraction is considerably more effective than when using a magnetic stirrer. The extract was subsequently centrifuged for 5 min (7,000 g) and the supernatant was filtered through a 0.20 μm disposable syringe membrane filter (Sartorius AG, Göttingen, Germany).

Sugars were represented as the sum of glucose, fructose, lactose and maltose while carbohydrates are treated as the sum of sugars and starch.

Cholesterol was determined by HRGC according to the AOAC 976.26 Method (2003). Analytical grade reagents were used as standards (Sigma-Aldrich Corporation, Milan, Italy).

Image and texture analyses

Bread-sticks used for texture analysis were stored at 20°C and 20% relative humidity and analysed no more than 24 h after production.

The moisture content of each sample was determined before texture analysis according to the AACC methods 44-15A (AACC, 2000).

Five cut specimens (10 mm long) were obtained from each sample to give a total of 250 replicates for each class. Each specimen was cut from the centre of different bread-sticks with an electric hacksaw.

Geometrical measurements of the samples to be tested were taken by means of image analysis techniques. The cross-section image of each side of a specimen was captured with an Epson Perfection 1650 scanner (Seiko-Epson Corporation, Nagano, Japan) at 12,800 dpi in a black and white photo with a 16-bit resolution. Digitalized pictures were analysed by means of the commercial software Sigma Scan Pro rel. 5.0 (Systat Software, Richmond, CA, USA). The cross-section area of the two sides was quantified and the mean value for each specimen was calculated.

For texture analysis, each specimen was analysed in the compression mode using a TA.XT2i Texture Analysis (Stable Micro Systems, Godalming, UK) fitted with a plate-plate geometry (Flat probe P/75; 75 mm diameter). The crosshead speed was 0.9 mm/s and data were acquired with a resolution of 500 Hz. All samples were analysed for 50% deformation.

For the acquisition of the compression stress-strain relationships, Texture Export Exceed software (Stable Micro Systems, Godalming, UK; release. 2.54) was used.

Following VALLES PAMIES *et al.* (2000) and PIAZZA *et al.* (2001), the following parameters were taken from the force/deformation curve:

* Number of spatial ruptures (mm^{-1}): $N_{sr} = N_0 / d$
* Average Puncturing Force (N): $F_m = A/d$
* Crispness work (N mm): $W_c = F_m / N_{sr}$
* Average drop-off (N): $F_s = \Sigma \Delta F / N_0$
* Maximum Force (N): F_{max}
* Fracture work (N mm): W_f
* Ruggedness adimensional index: $RI = l_r / d_r$

where N_0 is the total number of peaks,

d is the compression distance, F_{max} is the value of the higher compression peak, ΔF is the individual force drops for each peak from F_{max} to the defined final compression point, A is the area under the force deformation curve, W_f is the area under the first breaking point; l_r is the length of the line on the force/displacement plot encompassing from F_{max} to the end of the curve and calculated using the Pythagorian theorem ($L_r=\Sigma[(\Delta force)^2+(\Delta length)^2]^{0,5}$) and d_r is the real displacement of the dynamometer cross-head encompassing from F_{max} to the end of the compression curve.

Since the results of the texture analysis are directly correlated to sample humidity, all texture data taken or calculated from the stress/strain curves were normalised for sample humidity, i.e. the values were divided by the sample humidity. Instead F_m, W_c, F_s, F_{max} and W_f indexes were divided by the mean area value of each specimen.

Statistical analysis

Conventional statistical methods were used to obtain a basic statistical evaluation of the chemical and mechanical data. Analysis of Variance (ANOVA) was applied using STATISTICA for Windows Release 7.1 (StatSoft Inc., Tulsa, OK, USA) to determine differences between bread-sticks.

For the Artificial Neural Network (ANN), the software used was NeuroShell 2, Rel. 2 (Ward System Groups Inc., Frederick, MD, USA). The network architecture used was a three-layer, fully interconnected, feed-forward type with 7 nodes in the input, 16 in the hidden and 2 in the output layer. A learning rate of 0.1 and a momentum of 0.1 were used. For the input slab the linear activation function was used while the logistic functions were used for hidden and output layer slabs. Data set inputs were normalised in the -1/+1 range before use in training and testing of the ANN. To avoid network overtraining, NET-PERFECT™ was used. This is an implemented procedure of NeuroShell 2 that creates an entirely separate set of data, called test-set, and is used to evaluate how well the network is predicting. NET-PERFECT™ was used to compute the optimum point for saving the network when it is able to generalise new data well. Testing data were fed into test trained ANN after 200 training epochs. In particular, the network learning was carried out with a limit of 200,000 events after the minimum mean value of re-classification error of the test set was reached. All samples were used for ANNs. These samples were randomly subdivided into a training set (70%) and a validation set (30%). There were approximately 175 samples in the training set and 75 samples in the validation set. The percentage distribution of the samples between the two data sets was chosen empirically and was a compromise between the need to have the maximum number of samples in the training set, while at the same time having all product categories represented in the validation set. The ANN construction process, from the two data set extractions through learning, was repeated five times.

RESULTS AND DISCUSSION

Chemical evaluation

The composition of the typically-produced bread-sticks (Table 1) was similar to that of bread and crackers with low water and fat contents. The standard deviation of data was very high as expected for an artisanal production, particularly due to the variability in the percentage and type of raw materials used by each producer. Hence, there was a statistically significant difference ($p<0.01$) between the stretched bread-sticks and the rolled bread-sticks only with respect to the moisture and protein contents. In

Table 1 - Chemical composition of stretched "Grissino stirato" bread-sticks and rolled "Rubatà" bread-sticks and results of the Analysis of Variance performed between the two products.

	Stretched bread-sticks		Rolled bread-sticks		Significance
	X	σ	X	σ	
Moisture (%)	6.63	1.51	8.62	2.32	**
Ash (without sodium chloride) (% dm)	0.44	0.30	0.62	0.40	*ns*
Energy (kcal/100 g)	369	28	349	28	**
Protein (%)	12.17	0.98	11.02	1.49	**
Carbohydrates (%)	64.90	3.92	64.35	4.46	*ns*
Sugars (%)	3.95	1.76	4.12	1.30	*ns*
Glucose (%)	0.46	0.52	0.73	1.14	*ns*
Fructose (%)	0.22	0.08	0.26	0.12	*ns*
Lactose (%)	0.12	0.03	0.14	0.04	*ns*
Maltose (%)	3.42	1.60	3.31	0.98	*ns*
Starch (%)	60.95	4.67	60.23	4.91	*ns*
Fat (%)	6.70	3.62	5.25	2.68	*ns*
Cholesterol (mg/100 g)	4.07	4.26	3.55	2.49	*ns*

(X mean; σ standard deviation; dm dry matter; ** p<0.01; *ns* not significant).

particular, the stretched bread-sticks had the highest protein content, while the rolled bread-sticks had the highest moisture content.

Mechanical evaluation

Bread-sticks have a rigid, slightly-deformable, stiff structure that suddenly collapses with a brittle fracture and a peculiar decay of the forces after the starting fracture point [i.e. the maximum stress (F_{max}) applied in the compression mode test]. Fig. 1 shows typical compression curves for the two types of bread-sticks which are characterised by three zones: 1) a steep ascent of stress with strain culminating in a fracture; 2) a jagged oscillating stress-strain function for a considerable strain range that expresses the crack propagation in crisp structures and involves cell wall break-

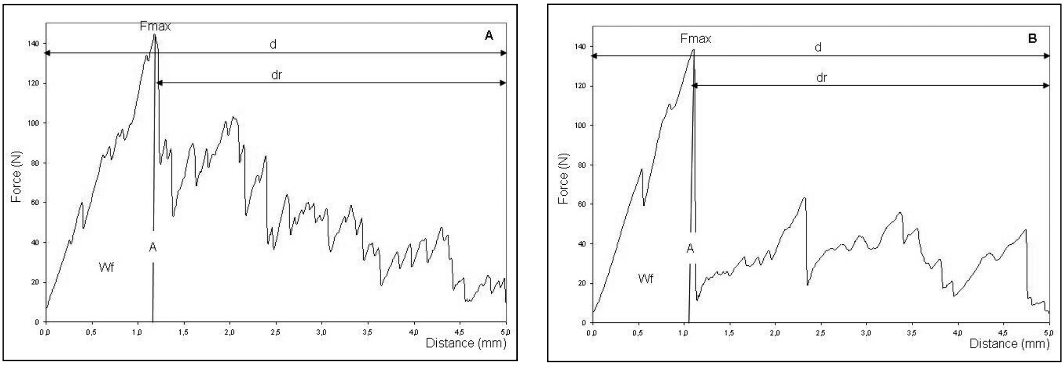


Fig. 1 - Typical force-deformation curves for "Grissino stirato" (A) and "Rubatà" (B) bread-sticks. For symbols see text.

age and 3) a second steep stress with ascent trend (PIAZZA *et al.*, 2001). High values of jaggedness, typical of low moisture foods, are present for both stretched and rolled bread-sticks (BARRETT *et al.*, 1992; ROHDE *et al.*, 1993). Instrumental parameters of crispness are summarised in Table 2. Differences in the shape and in the amplitudes of the force-deformation curves are reflected in the calculated parameters that were tentatively chosen to quantify the brittle fracture behaviour.

The well-established influence of water on all these parameters was taken into consideration by normalising the data on water content. The final moisture content of bread-sticks accounts for both compositional differences, as well as baking time-temperature conditions. This artefact allows the quantified mechanical parameters to be related to the intrinsic and typical macro-structure of the products. The extremely high level of the standard deviation of the mean values for each parameter within the same product typology is due to variation in the composition of bread-sticks from the various manufacturers and the different traditions in the territory. So, the aim of this work was to try to classify these traditional products on the basis of objective measurements, notwithstanding the variability in the particular traditional recipe and processing.

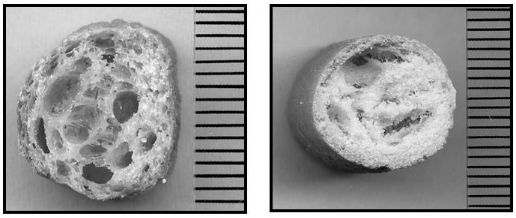
The number of spatial ruptures (N_{sr}) and the ruggedness index (RI) were higher for the stretched "Grissino stirato" bread-stick. This product is characterised by higher porosity compared to the rolled "Rubatà" bread-stick, due to larger cells with thin walls (Fig. 2). On the other hand, the rolling mode applied in the shaping step of the production technology results, from a macro-structure point of view, in a more regular sponge-like network.

The higher values of the maximum force (Fmax), the average drop-off (F_s) and the average puncturing force (F_m) indicate that the porous structure of the rolled "Rubatà" bread-stick is firmer than that of the stretched "Grissino stirato" one. Work (W_c) is a derived parameter of crispness ($W_c = F_m/N_{sr}$). Its significance might be doubtful because of the extremely high level of the statistical standard deviation, but its mean values differentiate the rolled bread-sticks and classify them as the less crisp product.

Table 2 - Values of the mechanical parameters for stretched "Grissino stirato" bread-sticks and rolled "Rubatà" bread-sticks and results of the Analysis of Variance performed between the two products.

	Stretched bread-sticks		Rolled bread-sticks		Significance
	X	σ	X	σ	
N_{sr}	1.172	0.467	0.716	0.316	**
F_m (× 10E5)	4.788	2.519	7.697	4.988	**
W_c (× 10E3)	5.062	0.478	1.099	2.032	**
F_s	0.011	0.006	0.015	0.013	**
RI	28.208	11.785	21.613	10.98	**
F_{max}	0.151	0.081	0.229	0.117	**
W_f (× 10E5)	8.767	5.413	14.75	13.45	**

(X-mean; σ-standard deviation; ** p<0.01).
Legend (see text for definitions): N_{sr}: Number of spatial ruptures (mm^{-1}); F_m: Average Puncturing Force (N); W_c: Crispness work (N mm); F_s: Average drop-off (N); RI: Ruggedness adimensional index; F_{max}: Maximum Force (N); W_f: Fracture work (N mm).



A B

Fig. 2 - Digitalized images of stretched "Grissino stirato" bread-stick (A) and rolled "Rubatà" bread-stick (B) sections.

The degree of jaggedness of the force-deformation curves for numerous cooked crisp cereal foods (crackers, snack foods, puffed extrudates and bread-sticks) has been quantified by using various approaches, in particular, Fractal Analysis and Fast Fourier Transform Analysis (BARRETT *et al.*, 1992; SCHER *et al.*, 2004) or peak analysis (SRISAWAS *et al.*, 2003). In this work the peak analysis approach was used and the results were then examined with ANNs.

ANNs constructed with the experimental texture analysis parameters show a very high average learning (94% for the rolled "Rubatà" bread-stick and 93% for the stretched "Grissino stirato" bread-stick) with small problems in the ANNs self-reconfiguration and only 6-7% reclassification errors. To evaluate the importance of each textural parameter on ANNs activities their "node weights" for input layers were extracted for each cycle and mean values for the five learning process were calculated (Table 3). As the total weight for each input neuron is directly correlated to the weight of the connection and the network structure the most important parameters for the ANNs construction are N_{sr}, F_m, F_{max} and W_c, while F_s, RI and W_f are less important. This confirms the texture differences between the two classes of products; in particular the rolled "Rubatà" bread-stick has a higher hardness attribute and the stretched "Grissino stirato" bread-stick has a higher friability.

CONCLUSIONS

Food authenticity and the determination of the geographic origin are two aspects that are receiving increased attention in food technology. In the bakery product sector, due to the absence of a definite production protocol for traditional, regional and home-made bread-sticks, many imitations have been produced to the detriment of the Piedmont producers and the image of this product.

Results obtained in this work do not definitively solve authenticity problems, but they clearly show that the traditional stretched "Grissino stirato" and traditional rolled "Rubatà" bread-sticks are two well-defined, distinguishable bakery products even though the artisan manufacturers' production modes are responsible for high variability.

Texture analysis performed by means of an objective instrumental method is a consolidated approach for quantifying the crispness attributes of these types of low-moisture bakery products and can define their characteristics, above all when combined with advanced ANN models. With this approach a mathematical model can be defined that can also be applied by food regulation authorities for product authentication. In particular rolled bread-sticks are stiffer

Table 3 - Values of weight coefficient calculated for the mechanical parameters used in the ANNs.

N_{sr}	0.458
F_m	0.323
W_c	0.318
F_s	0.194
RI	0.217
F_{max}	0.279
W_f	0.215

Legend (see text for definitions): N_{sr}: Number of spatial ruptures (mm^{-1}); F_m: Average Puncturing Force (N); W_c: Crispness work (N mm); F_s: Average drop-off (N); RI: Ruggedness adimensional index; F_{max}: Maximum Force (N); W_f: Fracture work (N mm).

than stretched bread-sticks which, on the other hand, are characterised by a higher crumbliness.

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