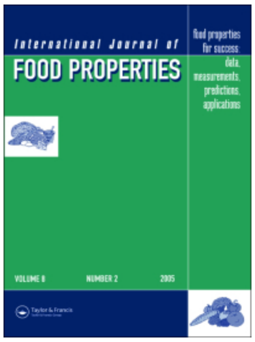

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Texture profile analysis of homogenized meat and plant-based patties

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ABSTRACT

The objective of this study has been to verify whether a combination of the standard Texture Profile Analysis and the back extrusion, which we have named "TPAH" since the analysis was performed after homogenization, can be applied to products that are difficult to handle. The TPAH was applied to 180 samples, divided equally into 18 batches of home-made pea-based patties, commercially pea-based patties, and meat patties. Seven TPAH parameters were measured on both raw and cooked samples: adhesiveness, chewiness, cohesiveness, gumminess, hardness, springiness and resilience. The specific density of the raw and cooked samples as well as a few physico-chemical parameters were also measured. All TPAH parameters were able to clearly discriminate between home-made, commercial, and meat patties (P-value <.05 to 0.001). A Canonical Discriminant Analysis highlighted the effectiveness of TPAH on both raw patties ($R^2 = 0.960$, Wilks' Lamba test Pr < 0.0001) and cooked ones ($R^2 = 0.955$, Wilks' Lamba test Pr < 0.0001). Even when the Canonical Discriminant Analysis was narrowed to cooked plant-based patties, the method proved to be efficient ($R^2 = 0.809$, Wilks' Lamba test Pr < 0.0001). The protein content was significantly related to all the TPAH parameters, except for adhesiveness. The TPAH method could be useful in research related to the substitution of meat patties with plant-based ones.

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Introduction

Meat analogs and plant-based patties (PBP) are emerging as strong competitors to meat and meat patties (MP) for environmental, social, and ethical reasons. Consequently, there is a growing interest in studies aimed at improving textural and sensory attributes in plant-based patties that are able to offer consumers the same taste sensations as those of meat patties.[1]

Texture plays an important role in food products.[2] The texture of meat and meat analogues is one of the most important eating qualities that manufacturers and researchers focus on. In fact, texture plays a significant role in the production of both raw and cooked plant-based patties that can make consumer feel they are actually eating a meat product. The texture and color of a raw patty need to resemble those of a meat patty to encourage its purchase. Moreover, the texture of a cooked product should offer the consumer the perception of eating a meat product. However, one of the problems related to creating a meat analog or meat patties is their semi-solid consistency, which makes some instrumental measurements, including the TPA, difficult.

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The most frequently used method for such a measurement is Texture Profile Analysis (TPA), which is an instrumental test that was originally developed at the General Foods Corporation Technical Centre by Friedman *et al.*[3] It provides objective measurements of texture parameters (a major factor of food acceptability) correlated with a sensory evaluation. It has been defined as a two-cycle compression, which is performed to simulate successive "bites and chews." This texture assessment technique is fundamentally based on the flow/deformation behavior of a soft food and on the deformation/fracture behavior of a solid food,[4] and therefore mimics the chewing process that takes place in the human mouth.

The correlation between instrumental texture profiling tests and sensory perceptions has been confirmed for solid, semi-solid, creamy, and liquid foods in several research activities.[5–8] Furthermore, texture changes and perceptions have been investigated for different kinds of foods during oral processing. Some researchers used an artificial mouth simulator with artificial saliva to simulate chewing, in order to correspond to oral processing,[9,10] and significant correlations were found between instrumental TPA and oral processing behavior.[11]

Traditionally, TPA requires a whole meat steak or a whole patty, both of which are in a destroyed condition at the end of the test. In this study, a protocol that involved homogenization of the sample was applied to evaluate the juiciness of raw and cooked plant-based and meat patties.[12] However, in order to address a cost reduction, we have embarked on a study that involves a novel approach: a combined process of Texture Profile Analysis (TPA) and back extrusion on the remains of the homogenized samples. This hybrid process, termed TPAH, was prompted by the observation of distinct textural variations among different patty types, even when rendered excessively soft after thawing. In addition, the coarse texture of some plant-based patties, including the presence of lumps, especially fat, made it difficult to repeat the TPA on the original patty.

The primary objective of this study has been to assess the efficacy of combining Texture Profile Analysis and back extrusion techniques to characterize the texture of homogenized meat and plant-based patties, particularly when dealing with products that present handling challenges. This method has significant potential for the analysis of plant-based patties and has offered insights into the development of novel products that are aimed at achieving a closer resemblance with traditional meat patties.

Materials and methods

Samples and preparation

Eighteen types of patties were examined: three commercial plant-based patties, purchased from a market (two batches of the same product, CB1 and CB2; and a precooked commercial one, CE); two home-made meat patties (MP1, MP2; 60% beef, 40% pork); 13 different home-made PBPs (P01 to P13). The PBPs were formulated using combinations of pea protein ingredients (textured and/or isolates), sunflower oil, canola oil, solid coconut fat and/or hydro coconut oil, fiber and water. Various preparation methods were employed to achieve structural variability. As stated on the ingredient labels, the CB patties contained 16 g of protein (pea and wheat proteins) and 13 g of fat (rapeseed and coconut oils) in each 100 g of product, whereas the CE patties contained 17.7 g of protein (pea protein) and 17.7 g of fat (canola, coconut, and sunflower oils).

A total number of 180 patties, which were divided equally by type and batch (10 patties/replications) were analyzed to obtain five physico-chemical parameters and eight TPAH parameters.[12,13] The patties were stored in a freezer at -20°C and analyzed after 9 h of thawing in a refrigerator at 3–4°C.

Two portions were obtained from each patty, and these portions were used for the analysis of the raw and cooked products. Few grams of the raw portion were used to obtain the total moisture content and the remaining raw part was homogenized for TPAH analysis. After the analysis, the same homogenized raw part was freeze-dried, before undergoing protein and fat determinations. Two 1 cm-thick discs (2500 mm^2 each) were obtained from the other portion, and these were cooked in a ventilated oven at

165°C until reaching an internal temperature of 72°C, as per the methodology outlined in reference.[14] These discs were then cooled before the subsequent analytical procedures. The cooled cooked residue was homogenized for TPAH analysis, then freeze-dried and subjected to protein and fat analyses.

Physico-chemical analyses

Certain instrumental analyses, which are expected to give results related to the texture,[15,16] were performed to explain the effectiveness of the TPAH on the homogenized meat and plant-based samples: (i) the total moisture content was measured on frozen samples (tmc): an 8–9 g portion was cut from a frozen patty, weighed, and placed in an oven, preheated to 125°C, for at least 4 hours and then, weighed again. The tmc (%) was considered as the difference in weight loss of the frozen portion expressed as the % of the raw weight (WB, wet basis); (ii) cooking shrinkage (mcs) was measured on a 1 cm thick disc, according to the method of Barbera and Tassone,[14] and expressed as the % of the raw area; (iii) of the second 1 cm thick cooked disc, a small portion (4–5 g) was dried to determine the residual fluid or fluid to the mouth (ftm). Before measuring, the two discs were cooled for 20 min in two plastic Petri dishes containing blotting paper to obtain a stabilized weight, and the cooling loss fluid weight (Cf) was then noted. The ftm value, expressed as % WB, was corrected for the cooling loss as;

$$\mathrm{ftm}\,\% = (\mathrm{Cw} + \mathrm{Cf} - \mathrm{Dw})/\mathrm{Rw}^{*}100$$

where Cw stands for the cooked sample weight, Cf is the cooling loss fluid weight, Dw is the cooked dried sample weight, and Rw is the raw sample weight; the two cooked residue samples were homogenized for the TPAH analysis, and then freeze-dried; (iv) the fat (reetq, ceetq) and protein (rprtq, cprtq) contents, expressed as % on a wet basis, were measured, by means of the standard analysis methods[17] on the raw and cooked freeze-dried residue samples.

TPAH analysis

All the TPAH measurements were repeated on the raw and cooked patty portions. Each sample was homogenized in a Moulinex mixer (Moulinette 800W; 600 rpm) for 20 s and poured into a commercial 16 mL of volume plastic container. Since the dimensions of the circular frustum-shaped container (Figure 1) affected the results, the exact dimensions are indicated hereafter: lower and upper area radius and height (14.75, 16.75 and 21.00 mm, respectively). The container was placed in a stable position on the base of the texturometer to avoid any movement of the container during compression and thus to acquire unbiased parameters, which were obtained as the probe squeezed the sample. A noticeable difference in density was observed while preparing the homogenized sample. This parameter was therefore measured on both the raw and cooked samples by weighing them and dividing the obtained value by the known volume, that is, 16 mL. A double compression cycle test was performed using a texture profile analyzer (type Instron 5543): compression at 50% of the sample height, with a 11.2 mm diameter stainless-steel probe, followed by a decompression (Figure 1). The cycle was performed without any delay between the first and the second compression, and the speed of the crosshead was set at 200 mm/min.

TPA parameters

Eight TPA parameters were measured on each raw and cooked homogenized sample: the hardness value (hd, chd), which is the peak force obtained for the first compression of the product; cohesiveness (cen, ccen), which indicates how well the product withstands a second deformation relative to its behavior during the first deformation[2]; gumminess (hardness x cohesiveness – gm, cgm); springiness (sp, csp), which is also called elasticity, and indicates how well a product physically springs back after being deformed during the first compression; chewiness (gumminess x springiness – ch, cch); adhesiveness (ad, cad), or the negative force area for the first bite;

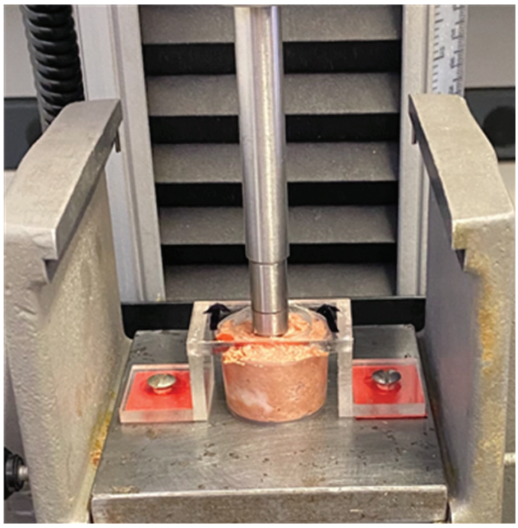

Figure 1. A 16 mL container fixed into the base of the texturometer to avoid the movement of the container during the decompression.

resilience (rsl, crsl), which is a measurement of how a sample recovers from deformation in relation to the speed and derived forces; plus the specific density (dns, cdns). Chewiness was also included in our study, even though some authors have stated that chewiness should only be considered for solid foods.

Statistical analyses

Statistical analyses were conducted, using SAS 9.4 and Rstudio, according to the following procedures: GLM, Simple Correlation, and Canonical Discriminant Analysis (CDA). CDA is a dimension-reduction technique that is related to principal component analysis and to the canonical correlation procedure, which is aimed at finding linear combinations of the quantitative variables that provide the maximal separation between classes or groups.

Results

Instrumental physico-chemical properties of the meat and the plant-based patties

Total moisture content: The commercial plant-based precooked CE patty was characterized by a relatively low tmc (53.6%) (Table 1). Moreover, the tmc values of the two meat patties were 61.3 and 71.0%, and this significant difference was because they were from two different beef and pork batches purchased on the market. The two batches were prepared with the same beef and pork ratios, but at different times, and the visual analysis showed a difference in both the color and visible fat contents. The other PBP types had an average tmc of 61.4%, which ranged from 58.6 to 66.4% (P09 and P07, respectively). In order to simplify the presentation of the results, the different types of patties were all compared as groups: MP1 *vs* MP2, MP *vs* PBP, MP *vs* CB, MP *vs* CE, MP *vs* home-made PBP (spPBP), CE *vs* CB, CB1 *vs* CB2, spPBP *vs* CB, and spPBP *vs* CE. All the groups were significantly different, except for the two CBs (Table 2).

Fluid to the mouth – The average ftm was 48.0%, and varied from 41.4% for MP1 to 54.7% for P07. CE and the CB2 had the lowest ftm of the various PBPs. A comparison of the various groups revealed a significant difference between the following groups: MP1 *vs* MP2, MP *vs* PBP, MP *vs* CB, MP *vs* spPBP, CB1 *vs* CB2, spPBP *vs* CB, and spPBP *vs* CE (Table 2).

Table 1. Physico-chemical parameters (mean ± SD) of raw and cooked meat and plant-based patties (% WB).

Types	tmc	ftm	mcs % RA	rprtq	reetq	cprtq	ceetq
MP1	61.3 ± 1.37	41.4 ± 1.11	25.0 ± 2.14	16.2 ± 0.73	15.8 ± 0.59	19.4 ± .63	12.4 ± 0.71
MP2	71.0 ± 0.55	47.6 ± 3.49	23.8 ± 1.98	19.0 ± 0.79	6.0 ± 0.36	19.3 ± 1.02	5.8 ± 0.32
CB1	60.6 ± 0.92	47.3 ± 2.49	10.3 ± 2.80	15.0 ± 0.58	14.8 ± 0.90	16.7 ± 0.77	11.9 ± 0.86
CB2	60.0 ± 0.77	44.8 ± 1.08	13.5 ± 2.40	15.7 ± 1.05	16.4 ± 1.51	18.3 ± 0.84	12.7 ± 0.56
CE	53.6 ± 1.70	44.9 ± 1.34	7.9 ± 1.84	22.1 ± 1.61	7.5 ± 0.61	22.2 ± 0.95	7.3 ± 0.35
P01	66.0 ± 1.60	50.7 ± 3.27	12.8 ± 1.92	11.7 ± 1.15	12.1 ± 0.54	12.4 ± 0.92	9.8 ± 0.54
P02	65.6 ± 1.58	53.0 ± 1.55	13.1 ± 1.17	11.9 ± 0.76	12.0 ± 0.70	13.0 ± 0.75	9.5 ± 0.70
P03	62.3 ± 2.52	48.9 ± 0.91	11.7 ± 1.12	12.6 ± 0.55	12.9 ± 1.81	13.5 ± 1.24	10.7 ± 0.81
P04	63.7 ± 1.52	49.7 ± 3.86	12.7 ± 1.52	11.7 ± 1.38	13.8 ± 1.39	12.8 ± 0.78	10.8 ± 0.62
P05	63.0 ± 1.06	50.4 ± 2.16	13.8 ± 106	12.2 ± 1.53	15.0 ± 1.62	13.1 ± 0.88	10.9 ± 0.72
P06	62.4 ± 1.03	50.9 ± 1.58	11.5 ± 0.78	14.7 ± 0.85	11.6 ± 0.50	15.3 ± 0.75	9.4 ± 0.50
P07	66.4 ± 2.22	54.7 ± 1.95	12.5 ± 0.91	9.5 ± 0.89	13.1 ± 1.98	1.7 ± 0.77	10.0 ± 0.98
P08	58.9 ± 1.84	46.2 ± 1.58	10.7 ± 1.05	14.9 ± 1.14	15.5 ± 0.67	16.3 ± 1.02	12.4 ± 0.67
P09	58.6 ± 1.01	47.1 ± 1.05	9.5 ± 1.16	15.4 ± 0.68	15.8 ± 0.51	15.8 ± 0.88	13.3 ± 0.51
P10	59.8 ± 1.11	45.8 ± 1.48	10.1 ± 1.52	14.2 ± 1.14	16.1 ± 1.12	15.7 ± 0.86	12.7 ± 0.54
P11	59.0 ± 1.57	47.3 ± 1.31	11.4 ± 1.93	15.2 ± 0.96	15.0 ± 0.98	16.9 ± 0.91	12.1 ± 0.98
P12	61.8 ± 1.65	47.3 ± 1.62	12.2 ± 1.65	12.5 ± 0.87	17.4 ± 1.80	14.2 ± 1.09	13.6 ± 0.74
P13	61.8 ± 1.00	46.7 ± 1.32	12.1 ± 2.35	14.1 ± 1.24	15.7 ± 0.47	16.0 ± 2.17	11.9 ± 0.47

tmc = total moisture content; ftm = fluid to the mouth; mcs = meat cooking shrinkage as % of raw sample area (RA); rprtq = protein in the raw sample; reetq = fat in the raw sample; cprtq = protein in the cooked sample; ceetq = fat in the cooked sample.

Table 2. Estimated difference between the averages physico-chemical parameters (difference ± SE) of the raw and cooked types or batches and their significance (ex: MP *vs* spPBP is MP – spPBP).

Types	tmc	ftm	mcs	rprtq	reetq	cprtq	ceetq
MP1 vs MP2	-9.7 ± 0.74#	-6.2 ± 0.95#	1.2 ± 0.81	-2.9 ± 0.49#	9.8 ± 0.64#	0.1 ±0 .48	6.5 ± 0.32#
MP vs PBP	4.7 ± 0.39#	-4.0 ± 0.50#	12.8 ± 0.43#	3.6 ± 0.26#	-3.2 ± 0.34#	4.2 ± 0.25#	-2.1 ± 0.17#
MP vs CB	5.8 ± 0.53#	-1.5 ± 0.67^	12.5 ± 0.57#	2.3 ± 0.35#	-4.7 ± 0.46#	1.8 ± 0.34#	-3.2 ± 0.23#
MP vs CE	12.5 ± 0.62#	-0.4 ± 0.79	16.5 ± 0.67#	-4.5 ± 0.41#	3.4 ± 0.54#	-2.8 ± 0.40#	1.8 ± 0.27#
MP vs spPBP	3.9 ± 0.40#	-4.6 ± 0.51#	12.6 ± 0.43#	4.5 ± 0.26#	-3.5 ± 0.34#	5.1 ± 0.26#	-2.2 ± 0.17#
spPBP vs CB	1.9 ± 0.40#	3.1 ± 0.51#	-0.1 ± 0.43	-2.2 ± 0.26#	-1.2 ± 0.34#	-3.2 ± 0.26#	-1.0 ± 0.17#
spPBP vs CE	8.6 ± 0.51#	4.2 ± 0.66#	3.9 ± 0.56#	-9.0 ± 0.34#	6.9 ± 0.44#	-7.9 ± 0.33#	4.0 ± 0.22#
CE vs CB	-6.7 ± 0.62#	-1.1 ± 0.79	-4.0 ± 0.67#	6.8 ± 0.41#	-8.1 ± 0.54#	4.7 ± 0.40#	-5.0 ± 0.27#
CB1 vs CB2	0.6 ± 0.75	2.6 ± 0.95#	-3.1 ± 0.81#	-0.8 ± 0.49	-1.6 ± 0.64@	-1.6 ± 0.49#	0.8 ± 0.32

Pr > |t|: # <0.001, @ < 0.01, ^ <0.05. Based on the Estimate statement in GLM procedure.

Cooking shrinkage: A significant difference was found for mcs and for all the comparisons between the various groups, except for the following ones: MP1 *vs* MP2, and spPBP *vs* CB (Table 2). In these cases, the meat patties showed a greater shrinkage (24.5%) than the plant-based ones, which was more than double that of the average PBP (11.6%), while the pre-cooked CE showed the minimum value (7.9%). It should be pointed out that, in these cases, the meat contained almost the same amount of water (ftm), albeit in a lower volume, thus indicating a higher water retention capacity of the cooked product.

Protein: The protein content of the raw patties varied between 9.5 and 22.1% (P07 and CE, respectively), and all the comparisons between the various groups revealed a significant difference, except for the CB type. The protein content of the cooked patties varied between 10.7 and 22.2% (P07 and CE, respectively), and all the comparisons between the various groups revealed a significant difference, except for the meat patties (Table 1 and 2).

Fat: The fat content of the raw patties ranged from 6.0 to 17.4%, and from 5.8 to 13.6% for the cooked patties (MP2 and P12 for the raw and cooked samples, respectively). All the comparisons between the various groups revealed significant differences (Table 1 and 2). The fat content of the meat was particularly different, probably due to the different characteristics of the two batches, although the proportions of beef and pork were the same. The different fatty acid composition of the meat, compared to the PBP, should also be considered for the purposes of the TPAH. Such differences in the water, protein, and fat contents are expected to be revealed by the TPAH parameters to confirm the usefulness of the method.

TPAH: a classic TPA adapted for homogenized products

TPAH on raw homogenized samples: The evaluation of the raw texture (Table 3) using the TPAH showed that the commercial CE was the hardest (16.09 N), the gummiest (9.18 N) and, therefore, the chewiest (7.42 N) of all the patties. These results confirm the total moisture content of CE (53.6%), mcs (7.9%) and fat and protein content results of the raw product (7.5 and 22.1%, respectively), which were the most extreme values, compared to the meat and the plant-based patties. Since CE was a precooked burger, the results of the raw samples were expected. The other patties (meat, CB, and PBP) were more uniform and with an average hardness value of 3.05 ± 1.355 N, which ranged from 1.47 (CB2) to 4.93 N (P08). Moreover, they were also less chewy, less gummy, and less springy. The raw average density was 0.931 mg/mL. All the comparisons between the various groups (Table 4) revealed significant differences in: (i) hardness, except for MP *vs* PBP and the home-made PBPs (spPBP) *vs* CB; (ii) cohesiveness, MP *vs* CB, MP *vs* spPBP, spPBP *vs* CB and CE *vs* CB; (iii) resilience, MP1 *vs* MP2, MP *vs* CB, MP *vs* spPBP, spPBP *vs* CB, and CE *vs* CB; (iv) gumminess and chewiness for all the groups, except for MP *vs* PBP, due to the great variability within the PBP group; (v) adhesiveness for all the groups, except for MP *vs* CE and spPBP *vs* CE; (vi) springiness for all the groups; (vii) density for all the groups, except for between the two meat patties.

TPAH on cooked homogenized samples – the meat patties, when cooked, surpassed all the other types in terms of hardness, registering an average value of 28.56 N. The meat patties were also found to be the chewiest (11.65 N) and gummiest (15.33 N) within the group, although they were less springy (an average value of 0.76) than the CE (0.81) (Table 5). The home-made plant-based patties were not so different from each other, but they were different from the meat and commercial samples. Hardness, chewiness, and gumminess were the most noticeably different parameters.

The comparisons of the hardness between the various groups showed significant difference, except within the MP and CB batches (Table 6). A significant difference in cohesiveness was observed for the MP *vs* spPBP, CB and CE groups, due to a different response of the spPBP compared to the other two commercial PBPs. Resilience between MP, meat *vs* CB and CE was significantly different; CB and CE showed lower resilience than the spPBP. All the groups were significantly different as far as gumminess and chewiness are concerned, except within the MP and CB batches. Adhesiveness was significantly different among all the groups, except for MP *vs* CE, and for CB. Springiness was significantly different among all the groups, except for CB. Density was also significantly different between groups, except between the two meat groups and between the CB patties and spPBP *vs* CE.

Table 3. TPAH parameters on raw samples (mean ± SD).

Types	Hardness (N)	Cohesiveness (Ratio)	Resilience (Ratio)	Gumminess (N)	Chewiness (N)	Adhesiveness (J)	Springiness (Ratio)	Density mg/mL
MP1	4.79 ± 0.910	0.54 ± 0.113	0.84 ± 0.023	2.60 ± 0.589	2.30 ± 0.506	0.003 ± 0.001	0.89 ± 0.012	0.980 ± 0.012
MP2	3.12 ± 0.317	0.53 ± 0.060	0.88 ± 0.021	1.66 ± 0.198	1.46 ± 0.161	0.002 ± 0.000	0.88 ± 0.011	0.997 ± 0.026
CB1	3.59 ± 0.750	0.42 ± 0.096	0.83 ± 0.029	1.54 ± 0.633	1.45 ± 0.586	0.002 ± 0.001	0.94 ± 0.005	0.987 ± 0.019
CB2	1.47 ± 0.249	0.35 ± 0.040	0.84 ± 0.017	0.52 ± 0.111	0.49 ± 0.100	0.000 ± 0.000	0.95 ± 0.030	0.918 ± 0.052
CE	16.09 ± 2.289	0.57 ± 0.017	0.87 ± 0.011	9.18 ± 1.305	7.42 ± 0.987	0.003 ± 0.003	0.81 ± 0.012	1.045 ± 0.029
P01	2.16 ± 0.489	0.65 ± 0.096	0.89 ± 0.025	1.41 ± 0.342	1.32 ± 0.317	0.003 ± 0.001	0.94 ± 0.007	0.903 ± 0.022
P02	2.45 ± 0.421	0.60 ± 0.113	0.89 ± 0.025	1.46 ± 0.307	1.36 ± 0.286	0.003 ± 0.001	0.93 ± 0.008	0.893 ± 0.013
P03	3.98 ± 0.924	0.47 ± 0.063	0.86 ± 0.032	1.87 ± 0.425	1.74 ± 0.400	0.004 ± 0.001	0.93 ± 0.007	0.920 ± 0.033
P04	2.15 ± 0.521	0.68 ± 0.082	0.88 ± 0.029	1.47 ± 0.415	1.39 ± 0.382	0.003 ± 0.001	0.94 ± 0.007	0.926 ± 0.030
P05	2.36 ± 0.431	0.60 ± 0.089	0.89 ± 0.020	1.38 ± 0.103	1.30 ± 0.103	0.003 ± 0.001	0.94 ± 0.010	0.909 ± 0.048
P06	3.39 ± 0.815	0.55 ± 0.056	0.88 ± 0.019	1.87 ± 0.492	1.72 ± 0.438	0.004 ± 0.001	0.92 ± 0.008	0.917 ± 0.020
P07	1.69 ± 0.297	0.77 ± 0.109	0.91 ± 0.021	1.31 ± 0.306	1.25 ± 0.293	0.003 ± 0.000	0.95 ± 0.009	0.931 ± 0.046
P08	4.93 ± 1.810	0.55 ± 0.081	0.87 ± 0.031	2.73 ± 1.116	2.49 ± 1.005	0.006 ± 0.004	0.91 ± 0.009	0.912 ± 0.042
P09	4.57 ± 0.995	0.59 ± 0.037	0.86 ± 0.020	2.65 ± 0.494	2.45 ± 0.445	0.005 ± 0.001	0.92 ± 0.006	0.960 ± 0.034
P10	3.98 ± 0.774	0.65 ± 0.095	0.87 ± 0.028	2.55 ± 0.521	2.35 ± 0.466	0.005 ± 0.001	0.92 ± 0.012	0.940 ± 0.018
P11	2.97 ± 0.886	0.59 ± 0.083	0.90 ± 0.025	1.76 ± 0.601	1.62 ± 0.548	0.003 ± 0.001	0.92 ± 0.007	0.839 ± 0.043
P12	1.56 ± 0.512	0.50 ± 0.048	0.85 ± 0.023	0.77 ± 0.210	0.73 ± 0.193	0.002 ± 0.000	0.96 ± 0.008	0.937 ± 0.030
P13	2.04 ± 0.249	0.59 ± 0.120	0.87 ± 0.051	1.21 ± 0.314	1.13 ± 0.279	0.003 ± 0.000	0.94 ± 0.014	0.879 ± 0.070

Table 4. Estimated difference between the averages TPAH parameters (difference ± SE) of the raw types or batches and their significance (ex: MP *vs* spPBP is MP – spPBP).

Types	Hardness (N)	Cohesiveness (Ratio)	Resilience (Ratio)	Gumminess (N)	Chewiness (N)	Adhesiveness (J)	Springiness (Ratio)	Density mg/mL
MP1 vs MP2	1.7 ± 0.45#	0.01 ± 0.040	-0.04 ± 0.012#	0.9 ± 0.27#	0.8 ± 0.24#	0.001 ± 0.0007^	0.01 ± 0.005#	-0.02 ± 0.017
MP vs PBP	0.2 ± 0.24	-0.03 ± 0.021	-0.01 ± 0.007	0.2 ± 0.14	-0.0 ± 0.13	-0.001 ± 0.0004^	-0.04 ± 0.003#	-0.06 ± 0.009#
MP vs CB	1.4 ± 0.32#	0.15 ± 0.028#	0.03 ± 0.009#	1.1 ± 0.19#	0.9 ± 0.17#	0.001 ± 0.0005^	-0.06 ± 0.004#	0.04 ± 0.012#
MP vs CE	-12.1 ± 0.37#	-0.04 ± 0.033	-0.01 ± 0.010	-7.1 ± 0.23#	-5.5 ± 0.20#	-0.000 ± 0.0006	0.08 ± .0.004#	-0.06 ± 0.014#
MP vs spPBP	1.0 ± 0.24#	-0.06 ± 0.021#	-0.02 ± 0.007#	0.4 ± 0.15#	0.3 ± 0.13^	-0.001 ± 0.0004#	-0.05 ± 0.003#	0.08 ± 0.009#
spPBP vs CB	0.4 ± 0.24	0.21 ± 0.021#	0.04 ± 0.007#	0.7 ± 0.15#	0.6 ± 0.13#	0.002 ± 0.0004#	-0.01 ± 0.003#	-0.04 ± 0.009#
spPBP vs CE	-13.1 ± 0.31#	0.03 ± 0.027	0.01 ± 0.009	-7.5 ± 0.19#	-5.8 ± 0.16#	0.001 ± 0.0005	0.13 ± 0.004#	-0.13 ± 0.012#
CE vs CB	13.6 ± 0.37#	0.19 ± 0.033#	0.03 ± 0.010#	8.1 ± 0.23#	6.5 ± 0.20#	0.001 ± 0.0006^	-0.13 ± 0.004#	0.09 ± 0.014#
CB1 vs CB2	2.1 ± 0.45#	0.07 ± 0.040	-0.01 ± 0.012	1.0 ± 0.27#	1.0 ± 0.24#	0.002 ± 0.0007^	-0.01 ± 0.005^	0.07 ± 0.017#

Pr > |t|: # <0.001, @ < 0.01, ^ <0.05. Based on the Estimate statement in GLM procedure.

Table 5. TPAH parameters on cooked samples (mean ± SD).

Types	Hardness (N)	Cohesiviness (Ratio)	Resilience (Ratio)	Gumminess (N)	Chewiness (N)	Adhesiveness (J)	Springiness (Ratio)	Density mg/mL
MP1	28.15 ± 4.084	0.50 ± 0.061	0.87 ± 0.017	14.78 ± 3.228	11.93 ± 2.412	-0.003 ± 0.006	0.809 ± 0.021	1.008 ± 0.024
MP2	29.06 ± 6.452	0.55 ± 0.101	0.89 ± 0.029	16.01 ± 4.568	11.30 ± 3.078	-0.019 ± 0.006	0.707 ± 0.036	1.009 ± 0.025
CB1	5.90 ± 1.227	0.47 ± 0.092	0.84 ± 0.024	2.69 ± 0.656	2.49 ± 0.591	0.003 ± 0.002	0.927 ± 0.008	1.009 ± 0.033
CB2	5.14 ± 0.770	0.43 ± 0.049	0.84 ± 0.019	2.18 ± 0.348	2.00 ± 0.321	0.003 ± 0.002	0.918 ± 0.007	0.999 ± 0.032
CE	25.05 ± 4.319	0.44 ± 0.041	0.83 ± 0.019	10.94 ± 1.448	8.84 ± 1.174	-0.011 ± 0.004	0.808 ± 0.030	0.979 ± 0.063
P01	5.51 ± 1.105	0.62 ± 0.084	0.88 ± 0.027	3.40 ± 0.657	3.07 ± 0.585	0.006 ± 0.001	0.902 ± 0.008	0.934 ± 0.023
P02	5.82 ± 0.908	0.55 ± 0.027	0.87 ± 0.014	3.21 ± 0.537	2.90 ± 0.486	0.006 ± 0.001	0.905 ± 0.011	0.951 ± 0.020
P03	9.84 ± 2.020	0.52 ± 0.064	0.87 ± 0.019	5.12 ± 1.175	4.63 ± 1.071	0.008 ± 0.004	0.904 ± 0.010	0.985 ± 0.040
P04	6.18 ± 1.149	0.58 ± 0.059	0.87 ± 0.018	3.53 ± 0.603	3.17 ± 0.540	0.006 ± 0.002	0.897 ± 0.012	0.956 ± 0.026
P05	6.97 ± 0.733	0.60 ± 0.061	0.88 ± 0.016	4.16 ± 0.471	3.71 ± 0.407	0.006 ± 0.002	0.890 ± 0.012	0.973 ± 0.026
P06	8.52 ± 1.052	0.59 ± 0.131	0.87 ± 0.019	5.05 ± 1.313	4.53 ± 1.181	0.009 ± 0.002	0.897 ± 0.007	0.979 ± 0.023
P07	4.62 ± 0.566	0.65 ± 0.045	0.88 ± 0.015	2.99 ± 0.385	2.62 ± 0.326	0.005 ± 0.001	0.878 ± 0.016	0.908 ± 0.038
P08	12.23 ± 1.910	0.54 ± 0.062	0.85 ± 0.014	6.61 ± 1.253	5.95 ± 1.128	0.010 ± 0.002	0.902 ± 0.006	1.013 ± 0.013
P09	11.27 ± 2.369	0.52 ± 0.052	0.85 ± 0.020	5.86 ± 1.112	5.30 ± 1.001	0.009 ± 0.002	0.905 ± 0.007	1.020 ± 0.027
P10	10.18 ± 1.943	0.56 ± 0.059	0.87 ± 0.015	5.72 ± 1.114	5.14 ± 0.986	0.008 ± 0.002	0.899 ± 0.007	1.026 ± 0.021
P11	9.74 ± 2.100	0.57 ± 0.066	0.88 ± 0.017	5.55 ± 1.090	5.00 ± 0.976	0.007 ± 0.003	0.901 ± 0.010	1.014 ± 0.027
P12	6.66 ± 1.128	0.59 ± 0.027	0.87 ± 0.009	3.89 ± 0.617	3.51 ± 0.566	0.006 ± 0.002	0.903 ± 0.007	1.004 ± 0.013
P13	10.41 ± 2.368	0.60 ± 0.088	0.89 ± 0.023	6.19 ± 1.231	5.40 ± 1.048	0.006 ± 0.003	0.873 ± 0.013	1.017 ± 0.016

Table 6. Estimated difference between the averages TPAH parameters (difference ± SE) of the cooked types or batches and their significance (ex: MP *vs* spPBP is MP – spPBP).

Types	Hardness (N)	Cohesiveness (Ratio)	Resilience (Ratio)	Gumminess (N)	Chewiness (N)	Adhesiveness (J)	Springiness (Ratio)	Density mg/mL
MP1 vs MP2	-0.9 ± 1.15	-0.05 ± 0.033	-0.02 ± 0.009^	-1.2 ± 0.72	0.6 ± 0.56	0.016 ± 0.0014#	0.10 ± 0.007#	-0.00 ± 0.014
MP vs PBP	19.6 ± 0.60#	-0.02 ± 0.017	0.01 ± 0.005^	10.6 ± 0.38#	7.4 ± 0.29#	-0.016 ± 0.0007#	-0.14 ± 0.004#	-0.02 ± 0.007#
MP vs CB	23.1 ± 0.81#	0.08 ± 0.023#	0.03 ± 0.006#	13.0 ± 0.51#	9.4 ± 0.39#	-0.014 ± 0.0001#	-0.16 ± 0.005#	0.00 ± 0.010
MP vs CE	3.6 ± 0.96#	0.09 ± 0.027#	0.05 ± 0.007#	4.4 ± 0.60#	2.8 ± 0.46#	0.000 ± 0.0012	-0.05 ± 0.006#	0.03 ± 0.012^
MP vs spPBP	20.3 ± 0.61#	-0.05 ± 0.017#	0.00 ± 0.005	10.7 ± 0.38#	7.4 ± 0.30#	-0.018 ± 0.0007#	-0.14 ± 0.004#	0.03 ± 0.007#
spPBP vs CB	2.8 ± 0.61#	0.13 ± 0.017#	0.03 ± 0.005#	2.3 ± 0.38#	2.0 ± 0.30#	0.004 ± 0.0007#	-0.03 ± 0.004#	-0.02 ± 0.007#
spPBP vs CE	-16.7 ± 0.79#	0.14 ± 0.023#	0.04 ± 0.006#	-6.2 ± 0.50#	-4.6 ± 0.38#	0.018 ± 0.0010#	0.09 ± 0.005#	0.00 ± 0.010
CE vs CB	19.5 ± 0.96#	-0.09 ± 0.027	-0.01 ± 0.007	8.5 ± 0.60#	6.6 ± 0.46#	-0.014 ± 0.0012#	-0.11 ± 0.006#	-0.02 ± 0.012^
CB1 vs CB2	0.8 ± 1.15	0.04 ± 0.033	-0.01 ± 0.009	0.5 ± 0.72	0.5 ± 0.56	0.000 ± 0.0014	-0.01 ± 0.007	0.01 ± 0.014

Pr > |t|: # <0.001, @ < 0.01, ^ <0.05. Based on the Estimate statement in GLM procedure.

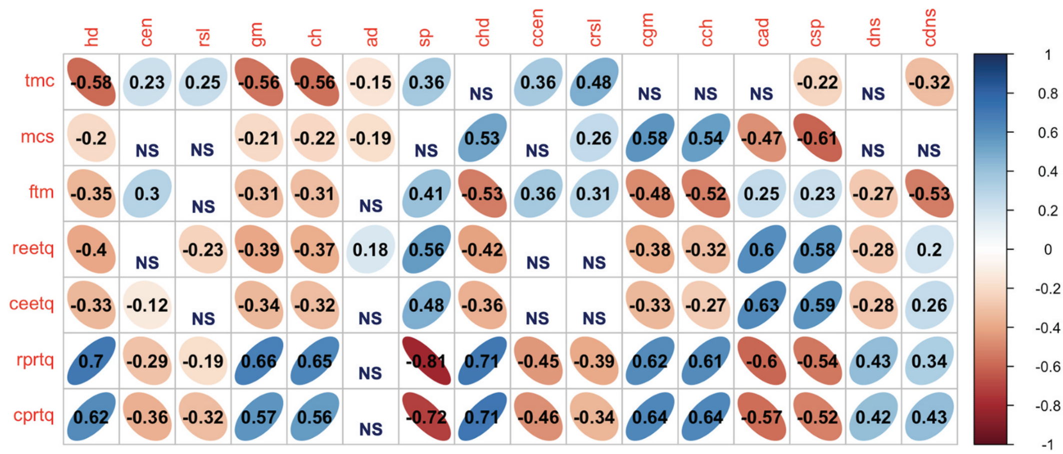

Figure 2. Pearson correlation between TPAH (raw and cooked: hd or chd = hardness, cen or ccen = cohesiveness, gm or cgm = gumminess, sp or csp s = pringiness, ch and cch = chewiness, ad and cad = adhesiveness, rsl and crsl = resilience, dns or cdns = density) and physico-chemical parameters (tmc = total moisture content, ftm = fluid to the mouth, mcs = meat cooking shrinkage, rprtq and cprtq = protein in the raw or cooked sample, reetq and ceetq = fat in the raw or cooked sample). NS is correlation not significant P-value >0.05.

Correlation between the physico-chemical and TPAH parameters

The simple correlations (Pearson correlation coefficient) between the physico-chemical parameters (tmc, mcs. ftm, fat and protein) and the TPAH parameters are shown in Figure 2 for the raw and cooked samples The protein content was significantly related to all the TPAH parameters, except for adhesiveness of the raw homogenized patties.

The hardness and the gumminess on the raw samples were adversely correlated with tmc (-0.58 and -0.56, respectively), ftm (-0.35 and -0.31), and fat (-0.40 and -0.39), but positively correlated with protein (0.70 and 0.66). Springiness was mainly positively correlated with tmc (0.36), ftm (0.41), and fat (0.56), but negatively correlated with protein (-0.81). Density was positively correlated with protein (0.43), but negatively correlated with ftm and fat (-0.27 and -0.28).

A different kind of behavior, related to the marked structural change in the meat patties was observed in the cooked samples. Hardness, gumminess, and chewiness were mostly negatively correlated with ftm (-0.53, -0.48 and -0.52, respectively) and fat (-0.36, -0.33 and -0.27), but positively correlated with mcs (0.53, 0.58 and 0.54) and protein (0.71, 0.64 and 0.64). Springiness was mostly positively correlated with fat (0.59), but negatively correlated with mcs and protein (-0.61 and -0.52). Density was positively correlated with protein (0.43), but negatively correlated with tmc and ftm (-0.32 and -0.53). Given the large number of parameters and types of patties, a multivariate approach was considered to be better to express the possible utility of the proposed method.

Multivariate analysis by means of canonical discriminant analysis (CDA)

In order to validate the efficiency of the TPAH method on the considered homogenized burger patties, CDA was applied to evaluate whether it was effectively able to discriminate between the types of patties. The results pertaining to the cooked products, which are of the greatest importance for production purposes, are presented in detail hereafter.

The plot in Figure 3a shows how the TPAH parameters measured on the cooked samples clearly discriminate the different types of patties. The R^2 between the first canonical variables and the type of patties is 0.955 (Wilks' Lamba test Pr < 0.0001), thereby explaining the 74.3% of the variability on the

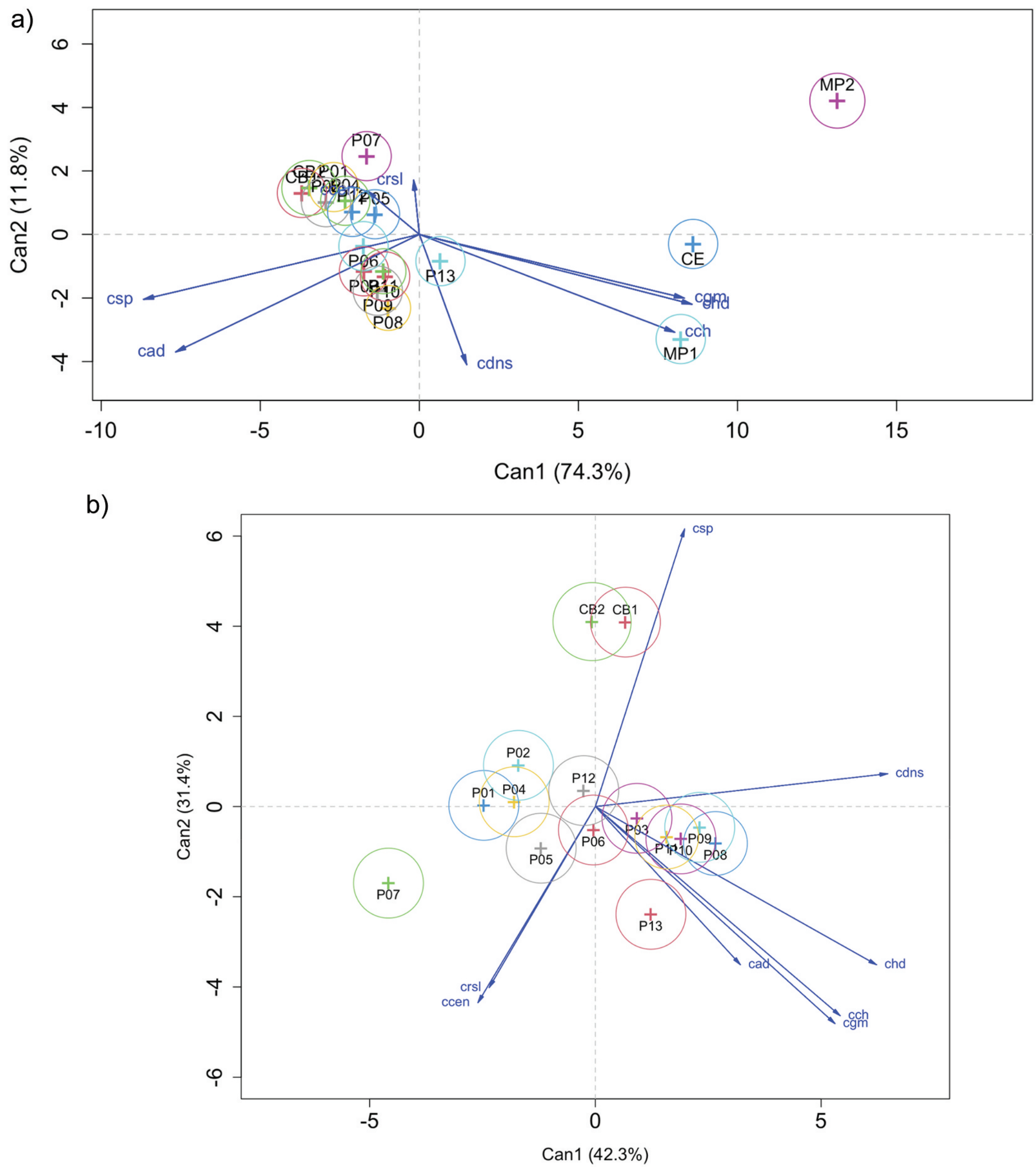

Figure 3. Plot of first two canonical variables (CDA) of TPAH parameters measured on cooked homogenized samples without MP and CE The names of the types of burgers are capitalized. In lower case the measured parameters (chd = hardness, ccen = cohesiveness, cgm = gumminess, csp = springiness, cch = chewiness, cad = adhesiveness, crsl = resilience, cdns = density).

first axis. The previously mentioned simple correlations between the TPAH parameters and some types of patties, such as MP and CE, are highlighted.

The CE and meat patties are mostly at a certain distance from the other patties, on the right side, while all the home-made PBPs and CB patties are on the left side. In order to better evaluate the method, CDA was applied without the CE and MP patties, since their characteristics are so different that they affected the results to a great extent. The obtained results show that the TPAH parameters are still able to separate plant-based patties into different groups ($R^2 = 0.809$, Wilks' Lamba test $Pr < 0.0001$), and to explain, with the first two canonical variables, 73.7% of the variability (Figure 3b). The commercial CB type is further differentiated from the home-

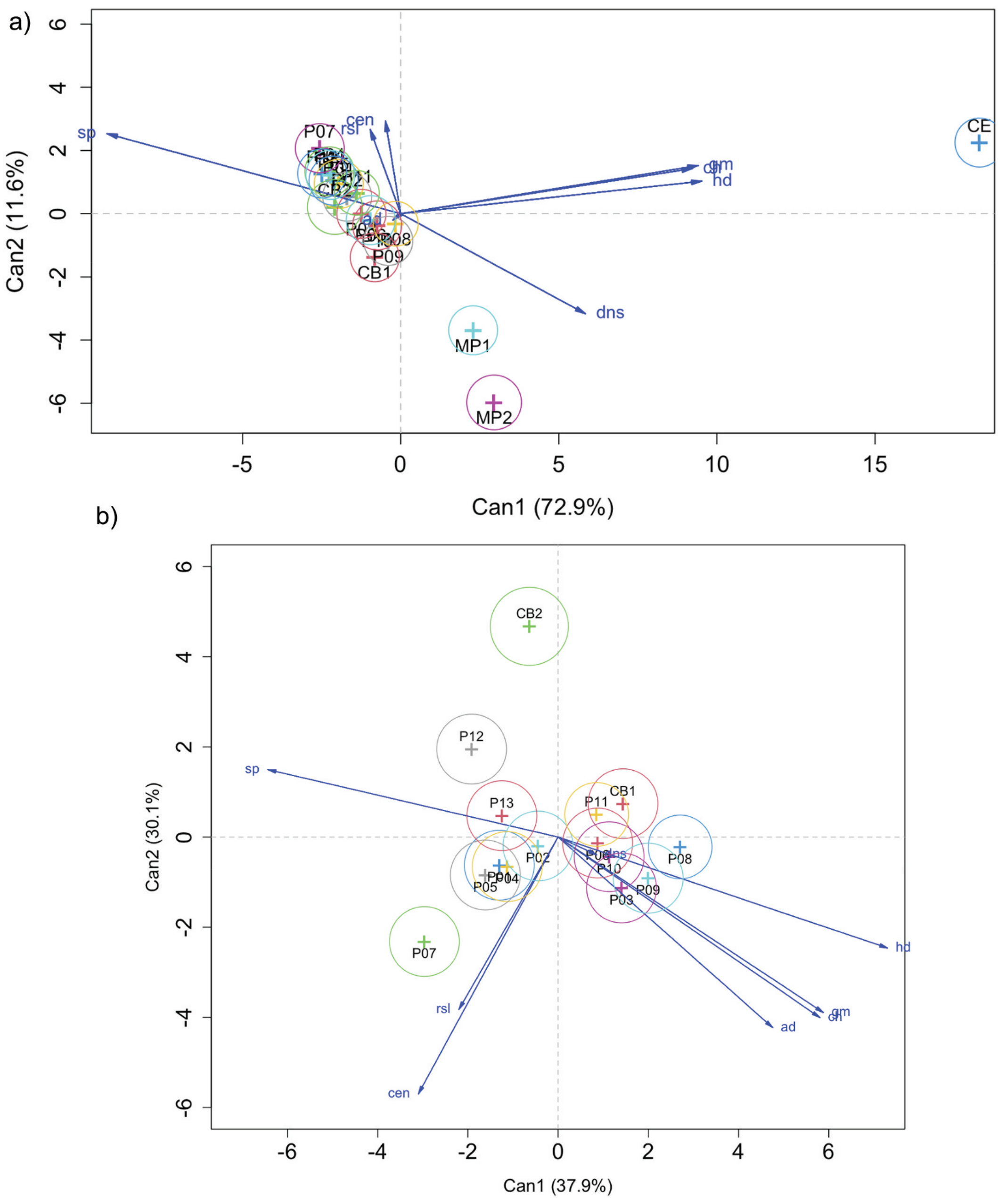

Figure 4. Plot of the first two canonical variables (CDA) of TPAH parameters measured on raw homogenized samples without MP and CE. The names of the types of patties are capitalized. In lower case the measured parameters (hd = hardness, cen = cohesiveness, gm = gumminess, sp = springiness, ch = chewiness, ad = adhesiveness, rsl = resilience, dns = density).

made types. Therefore, TPAH is even able to discriminate between the home-made types because they were prepared by varying the quantity of ingredients and methods of preparation.

Similar results are shown for the TPAH parameters measured on the raw patties ($R^2 = 0.960$, Wilks' Lamba test $Pr < 0.0001$), which explain 72.8% of the variability on the first axis. In this case, the CE type is positioned on its own at a distance from all the other types, and this is because it was precooked. The MP patties are like the plant-based patties and are positioned near the CB one (Figure 4a). In this case, the discrimination was once more focused on the central group and CDA was applied without the CE and MP patties. Again, the TPAH parameters separated the plant-based patties but with less precision ($R^2 = 0.744$, Wilks' Lamba test Pr < 0.0001) compared to the parameters measured on the cooked samples, where the first canonical variable explains the 37.8% of the variability (Figure 4b). A wider separation is shown among the two batches of the commercial CB type and spPBP.

Discussion

The texture of the patties was notably impacted by the diverse proportions of water, canola or coconut oil, and the additional constituents employed in crafting the spPBPs, which were designed to mimic the structural attributes of meat patties. These variables introduced complexities into the handling of the patties. It should be mentioned that some researchers,[18,19] performed a variation of TPA in a container with a close-fitting plunger, mainly on semi-solid foods, which allowed efficient back extrusion measurements to be made as the sample was compressed and forced to flow through an annular gap between the plunger and the container. Other researchers used a spherical or hemispherical-ended probe to make contact.[20] Therefore, we decided to use homogenized samples to facilitated the assessment of the TPA parameters to verify whether a combination of the 'back extrusion technique,[4] which requires a container for the product to be compressed, and the TPA, for which a material testing system (type Instron 5543) is utilized, could be useful (Figure 1).

There are no previous studies in the literature in which TPA was applied to homogenized patties or other homogenized products, although it has been applied for naturally liquid and semi-solid samples. Siraj[7] used a similar method for samples that did not hold their shape and applied TPA to a product that had been poured into a container.

An analysis of the textural parameters of the homogenized samples presented in Tables 3 and 5, shows that the different types of patties were discriminated. The idea of homogenizing a product prior to performing a texture analysis might initially appear counterintuitive, as it could suggest that the distinctive coarse textures and the effects of the utilized ingredients could be nullified as a result of the homogenization.

However, the tactile experience gained during the preparation of the samples for water content analysis revealed that the textural differences in products persisted after homogenization. In fact, when consumers chew a product – a process that emulates a form of homogenization – they are capable of clearly discerning the characteristics of a product. Indeed, Laurence *et al*.[21] reported that the texture variances, which are discernible in the initial bite of the meat, persist until the bite is swallowed, and a swallowable texture depends on the initial structure properties of the food.

Ili´c *et al*.[22] found that a great number of chews before swallowing was necessary for beef patties than for pea-based patties (31.0 *vs* 25.7). Our findings on hardness, gumminess and chewiness, confirmed this conclusion. According to Ismail *et al*,[23] the greater hardness of meat patties was due to the muscle protein denaturation phenomenon, which was also a consequence of the higher degree of shrinkage. This change in meat patties is shown by the TPAH method, which, in the experiment, allowed us to observe a huge difference between cooked meat and PB patties. However, after the meat patties and the precooked commercial patties were removed from the CDA, the clear and unexpected difference among the different PBPs was astounding. TPAH clearly placed the commercial patties at a great distance from the other PBPs (Figure 3b), thereby again highlighting the efficiency of the method. According to Vasanthi *et al*,[24] adhesiveness decreases as a result of a water and fluid loss, although the present study has shown no correlation with tmc for the cooked patties, but a significantly negative one with mcs, rprtq and cprtq (r = -0.47, -0.59 and -0.57, respectively; $P < .0001$) and a significantly positive one with reetq and ceetq (r = 0.60 and 0.63, respectively; $P < .0001$). Other authors have shown that an increase in the fat percentages is associated with lower hardness, gumminess, and chewiness values[25,26]; this study has confirmed the results associated with the fat level on raw samples (r = -0.40, -0.39 and -0.37, respectively) and cooked ones (r = -0.33, -0.34 and -0.32, respectively) (Figure 2). According to this small bibliographic review, the homogenization of a product does not appear to eliminate or alter the correlations with other instrumental parameters; the quality and/or quantity of the relationship changes but the relationship remains, thus indicating the efficiency of the method.

The acceptable differentiation between prototypes and even between batches that can be obtained through CDA analysis suggests that TPAH can differentiate among patties even after homogenization. Hence, correlations between the TPAH parameters and other instrumental parameters would seem to endorse the hypothesis that the homogenization of patties does not affect the description of the textural characteristics, and instead helps to avoid wasting material and time.

Conclusion

According to the obtained results, the TPAH method could be used for meat and plant-based patties which do not maintain their shape, thereby helping researchers to reduce the quantity of samples, time, and costs of the analyses. Homogenization was found to be the most practical and convenient solution to handle the commercially available and home-made plant-based samples, as well as the meat patties, because of their great heterogeneity pertaining to the fat particles, lumps and fibers. The homogenization of raw and cooked patties allows the texture of such products to be evaluate in another way. TPAH could be useful in research related to the production of plant-based patties as a substitute for meat ones. This need for a plant-based analogues, which comes from consumers is linked to an increasingly growing sensitivity toward environmental issues and attention to the welfare of the animals used for the meat production. There are currently some plant-based products on the market that resemble meat products, in terms of appearance, and sensory perception, but there is still room for qualitative improvements.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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Author's contributions

Conceptualization S.M. and S.B.; data curation S.B.; formal analysis S.M., S.B., S.G.P., S.T. and A.B.; writing-original draft: S.M., S.B, S.G.P., S.T. and A.B.; supervision, S.B. and S.M. All the authors have read and agreed to the published version of the manuscript.

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