

# Assessing texture profile analysis in natural state *versus* texture profile analysis with back extrusion post-homogenization of cooked pea protein-based and meat patties: A comparative study

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## ABSTRACT

This study aims to evaluate the efficacy of Texture Profile Analysis on homogenized cooked patties, referred to as TPAH, in accurately predicting patty texture and distinguishing between various patty types, similar to traditional TPA. Eight types of patties (96 samples), comprising one meat patty, one commercial pea protein-based patty, and six homemade pea protein-based patties, underwent analysis for hardness, cohesiveness, gumminess, chewiness, resilience, and springiness. All parameters measured by both methods exhibited similar variations, except for springiness. Homogenization maintained the ability to differentiate between different types of patties and generally reduced the load, albeit in a manner dependent on the type of product. For instance, the hardness decreased from 32.6 to 29.6 N for the meat patty, from 18.7 to 10.0 N for the homemade patties, and from 17.4 to 5.0 N for the commercial patty. The meat patty exhibited a greater consistency with a 9.2 % drop, while the homemade vegetable patties experienced a drop of 46.5 %, and the commercial patty even more so with 71.3 %. Canonical Discriminant Analysis applied to the two methods demonstrated the superior performance of TPAH compared to TPA. The TPAH method has proven to be valuable in predicting and comparing the texture of cooked patties.

## Introduction

The production of animal-derived products, particularly meat, has a significant impact on the environment. This impact is evident in the emission of greenhouse gases, extensive use of land and water resources, and high energy consumption (Steinfele et al., 2006; Stoll-Kleemann and O'riordan, 2015), along with implications for human health (Hu et al., 2019; Gibbs and Cappuccio, 2022; Grasso et al., 2021; Perraud et al., 2023). As a result, the shift from an animal-based diet to a pea protein-based diet is becoming increasingly important in addition to the valuable ingredients contained, such as carotenoids, polyphenols, and dietary fiber, that are beneficial for human health (Tuso et al., 2015; Kahleova et al., 2020; Messina et al., 2023).

Recent estimates predict an annual growth in the global demand for meat substitutes of 7.2 % in the period from 2021 to 2027 (Deshmukh et al., 2023), with the market size expected to increase from \$7.9 billion in 2022 to \$15.7 billion in 2027 (Watson, 2019).

Pea protein-based products are highly processed items crafted from

refined culinary ingredients, including purified or partially purified vegetable proteins, vegetable oils, binders, and minor components such as minerals, flavours, and colorants (Sha and Xiong, 2020). Pea protein-based meat alternatives are specifically designed to emulate meat in terms of appearance, texture, taste, and nutritional content to be readily embraced by consumers and offer a more convenient way to switch to a diet with a lower proportion of animal-based proteins. Notably, one of the most popular imitated meat products is the patty. Consequently, scientists, the food industry, chefs, and nutritionists have been actively engaged in replicating the desirable textural qualities of meat products due to their intricate structure (Madieta et al., 2011; Sha and Xiong, 2020; Szenderák et al., 2022; Younis et al., 2022).

The available methods for assessing the structural characteristics of food fall into two categories: sensory and instrumental methods. Instrumental methods are widely employed to predict the texture profile of food (Younis et al., 2022; Zhou et al., 2022). Compared to traditional sensory evaluation, instrumental methods are generally simpler, more practical, sometimes more cost-effective, highly sensitive, easily

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quantifiable, and less susceptible to subjective human judgments (Madieta et al., 2011; Contador et al., 2016).

Among the instrumental methods, Texture Profile Analysis (TPA) stands out as the most widely used, applicable to a broad range of solid and semi-solid foods. TPA offers high precision and a strong correlation with the reference method, outperforming other instrumental methods (Caine et al., 2003; De Huidobro et al., 2005; Novaković and Tomašević, 2017). TPA instruments replicate the chewing process by simulating the human mouth and exhibiting similar performance characteristics to the human jaw (Novaković and Tomašević, 2017). Nevertheless, the diverse consistency and composition of products can present challenges in measurement, rendering it difficult or even impractical for certain items, such as patties. Considering the composition of meat and pea protein-based patties, which may exhibit irregularities such as lumps, uneven fat distribution, or soft consistency, the application of classic Texture Profile Analysis becomes challenging. Mabrouki et al. (2023) proposed a solution by homogenizing samples before employing the TPA method, referred to as Texture Profile Analysis with Homogenization (TPAH). This method has proven to be descriptive and discriminant in differentiating between various types of patties.

The primary aim of this study is to examine the correlation between the classical TPA and the TPAH method introduced by Mabrouki et al. (2023), and to evaluate how these two approaches effectively differentiate the texture attributes of patties.

## Material and methods

### Raw materials

In this study, eight types of patties were prepared: six pea protein-based homemade types (HPBP) using our own formulations, labelled from P1 to P6; one commercially available pea protein-based type (CP); one homemade meat type (MP) composed of 60 % beef and 40 % pork. All the patties were cooked before the analysis.

The HPBPs were made by combining different percentages of commercial pea protein products, coconut oil, canola oil, fiber, water, and other minor ingredients (Table 1). The two pea protein products (Ntr, HME) were both present in the HPBP, but in different proportions. The Ntr consisted of a commercial textured pea protein product (containing 70 % of protein) added in a proportion between 0 and 18.6 % to improve texture and firmness of patties. The HME was a commercial high moisture extruded pea protein product added in a proportion between 6.0 to 40.7 %, to improve fibrosity and texture of patties. Various preparation protocols and recipes were used to achieve different structures and juiciness.

According to the nutrition facts, the commercial patty contained 17.7 g of protein (from pea protein) and 19.5 g of fat (from canola, and

coconut oils) per 100 g of product.

In this study, “HPBP” denotes homemade patties specifically crafted with pea protein-based ingredients, whereas “PBP” encompasses a wider scope, and referring to both homemade and commercially available pea protein-based patties.

### Texture profile analysis measurements

The TPA was conducted on a total of 48 samples, equally divided for each type. Patties were cooked on a grill for one minute on each side, then wrapped in foil and steamed for 12 min at 200 °C with 80 % of humidity. During the TPA measurements, the sample temperature was maintained at 50 °C. TPA was conducted by following established protocols (Caine et al., 2003; De Huidobro et al., 2005; Novaković and Tomašević, 2017).

### Texture profile analysis on homogenized samples measurements

The TPAH was applied to 48 patties equally distributed among the eight types. The patties were cooked in a convection oven at 165 °C until the internal temperature reached 72 °C, following a protocol adopted from Barbera and Tassone (2006). After cooking, the patties were ground and homogenized for 20 s using a Moulinette blender (Moulinette 800 W; 600 rpm). The homogenized samples were then transferred to a commercial plastic container with a volume of 15 mL (dimensions: lower and upper area radius of 14.54 mm and 15.61 mm, respectively; height 21 mm) and kept at room temperature (20–22 °C) until testing. An instrumental texture profile analyzer (Instron 5543 type), using a double uniaxial compression, was employed for TPAH. Standardized experimental conditions included compressing the sample with an 11.2 mm diameter stainless-steel probe, reducing it to 50 % of its original 21 mm height. There was no delay between the first and second compressions. The crosshead speed was set at 200 mm/min. To minimize movement affecting measurements, the container was securely fixed to the texturometer's base (Mabrouki et al., 2023).

### Measured parameters

Both methods were used to assess the same six parameters in the cooked samples, providing valuable insights into their texture and mechanical properties.

- Hardness (hd) - this parameter represents the peak force (N) experienced during the first compression.
- Cohesiveness (cen) - it indicates the product ability to withstand a second deformation and is calculated as the ratio between the area during the second compression and the area during the first compression.
- Gumminess (gm) - it is applicable primarily to semi-solid products and is calculated as the product of hardness and cohesiveness (N).
- Chewiness (ch) - it is relevant only to semi-solid products and is calculated as the product of gumminess and springiness (N).
- Resilience force (rsl) - it quantifies the sample's ability to recover from deformation (ratio).
- Springiness (sp) - it measures elasticity and is expressed as a ratio of the detected height during the second compression divided by the original height.

### Statistical analysis

The statistical analysis employed SAS 9.4 and R Studio software for robust assessment. Utilizing the General Linear Model, distinctions among patty types were thoroughly analyzed. Results are presented as mean values accompanied by standard deviations. Statistical significance was determined at a threshold of  $P < 0.05$ . Moreover, Pearson's correlation coefficient was computed to explore the relationship

**Table 1**  
Ingredients and composition of the pea protein-based homemade patties (%).

Ingredients and composition	P1	P2	P3	P4	P5	P6
Textured pea protein product (Ntr)	18.06	14.29	12.73	14.29	8.79	0.00
High moisture extruded pea protein product (HME)	6.02	14.29	12.73	14.29	26.37	40.72
High protein content product (80%)	0.00	0.00	2.00	0.00	0.00	2.00
Canola oil				8.00		
Hydrated coconut oil				8.00		
Beet juice				2.91		
Potato starch				0.34		
Pea fiber				0.47		
Other minor ingredients				up to 100%		
Water content	58.63	59.12	59.30	59.12	59.82	60.92
Protein content	14.65	14.76	14.83	14.76	14.94	15.25

between the texture profiles of non-homogenized and homogenized patties.

Furthermore, Canonical Discriminant Analysis (CDA) was implemented as a dimension-reduction technique akin to principal component analysis and canonical correlation procedures. Its primary objective was to identify linear combinations of quantitative variables maximizing differentiation between classes or groups.

## Results

### Overall effects of homogenization

Both the TPA and TPAH methods, despite employing two similar instruments, assess the same product but in entirely distinct states. TPA evaluates the patties in its original structural form, while TPAH evaluates them after homogenization. The homogenization step allows to reduce analysis costs, within a broader protocol, and to ease the handling of soft products and coarse structures. Consequently, it is expected that different values will be obtained for various parameters. However, the critical aspect remains to establish a substantial correlation among these parameters, and even more essential, to confirm whether TPAH effectively recognises different types of patties when applied.

Table 2 illustrates that, on average, the forces involved were significantly higher with TPA compared to TPAH. This was expected because TPA measures a solid substance while TPAH assesses a semi-solid one. The variability is considerably greater with the TPAH method than with TPA, roughly doubling on average. This elevated variability can be attributed to the homogenization effect. For instance, when measured with the TPAH method, the hardness varied from 29.6 to 5.0 N for meat and commercial patties, respectively, while the same parameter fluctuated from 32.6 to 17.4 N, when assessed using the TPA method (Table 3). It seems that the TPAH method amplifies the differences when measuring a force (hardness, gumminess, and chewiness).

### Hardness

The assessment of patty hardness using TPA revealed that the HPBPs (average of P1 up to P6) exhibited a similar hardness to the CP (18.7 N and 17.4 N, respectively) (Table 4). The MP showed a significantly higher hardness (32.6 N) compared to the PBP (18.5 N). Interestingly, the homogenization process did not eliminate the hardness of the MP (TPA = 32.6 N vs TPAH = 29.6 N). However, a substantial reduction in hardness was observed in the PBP (TPA = 18.5 N vs TPAH = 9.3 N).

After homogenization, the difference between MP and PBP remained, but a significant difference between CP and HPBP was also observed (Table 4). Homogenization has reduced hardness depending on the patty type. For MP, the decrease was only by 9.2 % whereas for HPBP, it was 46.5 %, and for CP, a substantial 71.3 %, compared to TPA values. A positive and significant correlation in hardness measured by the two methods was observed ( $r = 0.77$ ; Table 2).

**Table 2**

Average values, SD, Coefficient of Variability, test F TPA vs TPAH, and Person coefficient relating to the parameters ( $n = 96$ ) measured with the two methods TPA (Texture Profile Analysis) and TPAH (TPA on Homogenized patty).

Parameter	Unit	TPA		TPAH		P	r P<0.01
		Mean ± SD	CV	Mean ± SD	CV		
Hardness	N	20.3 ± 5.59	27.6	11.9 ± 7.81	65.8	<0.0001	0.77
Cohesiveness	Ratio	0.73±0.023	3.2	0.55±0.076	14.0	<0.0001	NS
Gumminess	N	14.8 ± 4.57	30.9	6.6 ± 4.57	69.8	<0.0001	0.79
Chewiness	N	11.6 ± 4.14	35.6	5.4 ± 3.04	55.8	<0.0001	0.73
Resilience force	Ratio	0.43±0.036	8.5	0.87±0.021	2.4	<0.0001	0.39
Springiness	Ratio	0.78±0.036	4.7	0.87±0.071	8.1	<0.0001	-0.72

### Cohesiveness

The cohesiveness, as measured by TPA, distinguished between meat-based patties and those made from vegetables. TPAH exhibited a significant difference between commercial and homemade patties, with the lowest value observed for CP, though it did not differentiate between MP and PBP.

### Gumminess

The gumminess analysis of non-homogenized patties showed that there was no significant difference between HPBP (13.4 N) and CP (12.6 N) whereas a significant difference was confirmed between MP and PBP, with gumminess about twice as large (25.2 N). Homogenization reduced the gumminess of MP from 25.2 to 16.8 N, of CP from 12.6 N to 2.1 N, and of HPBP from 13.4 to 5.6 N (Table 4). The difference between MP and HPBP remained after homogenization, and like hardness, there was a reduction by 33 % for MP, by 58 % for HPBP, and by 83 % for CP.

The gumminess of all the types of patties after homogenization was significantly positively correlated with that of non-homogenized patties ( $r = 0.79$ , Table 2).

### Chewiness

TPA showed that there was no significant statistical difference between the HPBP and CP (10.2 vs 10.1 N, respectively). However, the HPBP (10.2 N) could not mimic the chewiness of MP, which was about a half of the meat bite strength (21.4 N) (Table 4).

After the homogenization process, the absolute chewiness values decreased; however, TPAH still managed to detect a statistically significant difference between the MP and PBP. Additionally, TPAH revealed a noteworthy distinction between the commercial product and the homemade alternatives. The homogenization of patties appears to be effective in differentiating chewiness, and its efficacy was further confirmed by a positively significant correlation ( $r = 0.73$ ) between the two methods (Table 2).

### Resilience force

In the TPA measurement, the resilience force was significantly higher in MP than in PBP but did not differ between the commercial product and the homemade ones. After homogenization the resilience force increased for PBP and decreased for MP, and the TPAH was still able to significantly distinguish all the four groups (Table 4). The correlation between the two methods was positively significant, but not sufficiently high ( $r = 0.39$ ) (Table 2).

### Springiness

In the TPA, when comparing the various groups of patties, it was observed that HPBP exhibited a lower spring force (0.76) than CP (0.80) and MP (0.85). As depicted in Table 4, following homogenization, the springiness of MPs decreased from 0.85 to 0.69, whereas the PBP, on average, increased with a negative correlation ( $r = -0.72$ ) (Table 2).

**Table 3**

Summary of averages ( $\pm$ SD) textural properties for cooked patties according to the two methods (TPA = Texture Profile Analysis; TPAH = TPA on homogenized patties; MP = meat, CP = commercial, P1 to P6 = homemade pea protein-based patties;  $n = 48$ ).

Parameter (unit)	Method	MP	CP	P1	P2	P3	P4	P5	P6
Hardness (N)	TPAH	29.6 $\pm$ 7.52	5.0 $\pm$ 0.83	13.2 $\pm$ 1.47	10.8 $\pm$ 2.27	9.3 $\pm$ 2.08	10.5 $\pm$ 2.16	6.1 $\pm$ 0.96	10.6 $\pm$ 2.52
	TPA	32.6 $\pm$ 3.47	17.4 $\pm$ 1.30	17.7 $\pm$ 4.20	21.4 $\pm$ 1.02	19.6 $\pm$ 1.31	18.9 $\pm$ 1.11	14.0 $\pm$ 1.58	20.5 $\pm$ 2.29
Cohesiveness (Ratio)	TPAH	0.57 $\pm$ 0.094	0.43 $\pm$ 0.053	0.57 $\pm$ 0.071	0.51 $\pm$ 0.041	0.57 $\pm$ 0.077	0.58 $\pm$ 0.057	0.59 $\pm$ 0.033	0.55 $\pm$ 0.055
	TPA	0.78 $\pm$ 0.018	0.73 $\pm$ 0.01	0.71 $\pm$ 0.014	0.71 $\pm$ 0.008	0.71 $\pm$ 0.015	0.72 $\pm$ 0.008	0.72 $\pm$ 0.011	0.73 $\pm$ 0.008
Gumminess (N)	TPAH	16.8 $\pm$ 4.86	2.1 $\pm$ 0.36	7.4 $\pm$ 0.61	5.4 $\pm$ 1.00	5.2 $\pm$ 1.22	6.0 $\pm$ 1.05	3.6 $\pm$ 0.52	5.8 $\pm$ 1.31
	TPA	25.2 $\pm$ 2.57	12.6 $\pm$ 0.88	12.6 $\pm$ 3.16	15.3 $\pm$ 0.86	13.9 $\pm$ 1.08	13.6 $\pm$ 0.91	10.0 $\pm$ 1.04	15.0 $\pm$ 1.67
Chewiness (N)	TPAH	11.7 $\pm$ 3.42	2.0 $\pm$ 0.32	6.7 $\pm$ 0.57	4.9 $\pm$ 0.92	4.7 $\pm$ 1.07	5.4 $\pm$ 0.95	3.2 $\pm$ 0.47	5.0 $\pm$ 1.11
	TPA	21.4 $\pm$ 2.11	10.1 $\pm$ 0.91	9.5 $\pm$ 2.45	11.7 $\pm$ 0.83	10.4 $\pm$ 0.89	10.4 $\pm$ 0.74	7.7 $\pm$ 1.04	11.7 $\pm$ 1.52
Resilience force (Ratio)	TPAH	0.90 $\pm$ 0.020	0.85 $\pm$ 0.022	0.86 $\pm$ 0.018	0.86 $\pm$ 0.016	0.88 $\pm$ 0.016	0.87 $\pm$ 0.012	0.87 $\pm$ 0.010	0.88 $\pm$ 0.008
	TPA	0.51 $\pm$ 0.015	0.41 $\pm$ 0.011	0.40 $\pm$ 0.014	0.41 $\pm$ 0.012	0.41 $\pm$ 0.015	0.41 $\pm$ 0.010	0.42 $\pm$ 0.015	0.46 $\pm$ 0.014
Springiness (Ratio)	TPAH	0.69 $\pm$ 0.018	0.92 $\pm$ 0.005	0.90 $\pm$ 0.005	0.91 $\pm$ 0.008	0.90 $\pm$ 0.010	0.90 $\pm$ 0.012	0.90 $\pm$ 0.004	0.87 $\pm$ 0.012
	TPA	0.85 $\pm$ 0.017	0.80 $\pm$ 0.023	0.75 $\pm$ 0.016	0.77 $\pm$ 0.013	0.75 $\pm$ 0.010	0.77 $\pm$ 0.012	0.76 $\pm$ 0.037	0.78 $\pm$ 0.026

**Table 4**

Comparison of averages between the two methods (TPA = Texture Profile Analysis; TPAH = TPA on homogenized patty) in distinguishing the different types of patties: meat (MP), commercial (CP), homemade (HPBP), and pea protein-based patties (PBP;  $n = 48$ ).

Parameter	Method	MP	PBP	CP	HPBP	MP vs PBP	CP vs HPBP
Hardness (N)	TPAH	29.6	9.3	5.0	10.0	<0.0001	0.0008
	TPA	32.6	18.5	17.4	18.7	<0.0001	NS
Cohesiveness (Ratio)	TPAH	0.57	0.54	0.43	0.56	NS	<0.0001
	TPA	0.78	0.72	0.73	0.72	<0.0001	0.0363
Gumminess (N)	TPAH	16.8	5.1	2.1	5.6	<0.0001	0.0002
	TPA	25.2	13.3	12.6	13.4	<0.0001	NS
Chewiness (N)	TPAH	11.7	4.6	2.0	5.0	<0.0001	<0.0001
	TPA	21.4	10.2	10.1	10.2	<0.0001	NS
Resilience force (Ratio)	TPAH	0.90	0.87	0.85	0.87	0.0001	0.0013
	TPA	0.51	0.42	0.41	0.42	<0.0001	NS
Springiness (Ratio)	TPAH	0.69	0.90	0.92	0.90	<0.0001	<0.0001
	TPA	0.85	0.77	0.80	0.76	<0.0001	0.0008

This parameter, even after homogenization, retains its discriminating ability, albeit in a different manner compared to the TPA.

*Correlations between parameters measured by TPA and TPAH*

Fig. 1 shows the correlations between the various parameters measured with the two methods. All parameters measured with the TPAH, except for cohesiveness, showed significant correlations with the

ones measured by the TPA, with  $r$  values ranging from a negative correlation of  $-0.9$  (TPAH vs TPA: springiness vs chewiness) to  $0.79$  (TPAH vs TPA: hardness vs gumminess and chewiness; gumminess vs gumminess and chewiness).

It is noteworthy that the correlation between the same parameter remained consistently positive, with an average correlation coefficient ( $r$ ) of  $0.76$  for the three parameters: hardness, gumminess, and chewiness. This suggests that products characterized by higher levels of these three parameters tend to be measured similarly in both their original and homogenized states.

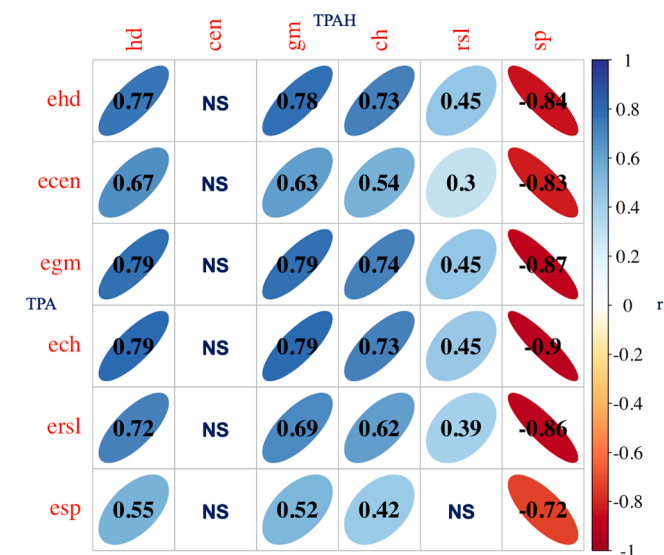
*Multivariate analysis of TPA and TPAH*

To further evaluate the efficacy of the TPAH method, the Canonical Discriminant Analysis (CDA) was applied and results of the TPA and TPAH were significantly correlated even when the structure was different (solid and homogenized). Furthermore, the TPAH method successfully recognized different types of patties such as the classic TPA.

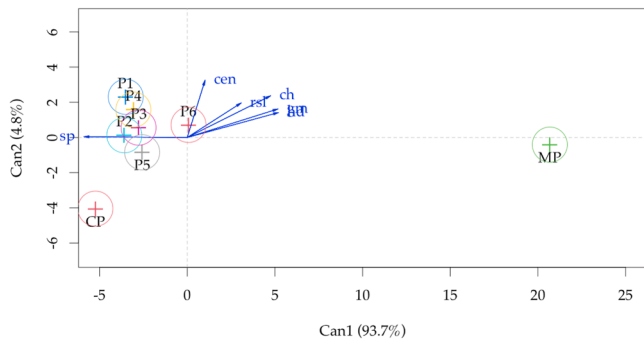
The multivariate correlation between the two methods showed an Adjusted Canonical Correlation for the first canonical variables of  $r = 0.97$ , which was much larger than the one of any other simple correlation (springiness vs chewiness,  $r = -0.90$ ).

Fig. 2 illustrates the distribution of the patty types across the first two axes using the TPAH method, while Fig. 3 depicts the CDA analysis conducted through the TPA method. TPA tends to confuse CP and P1, whereas TPAH provides better separation between them.

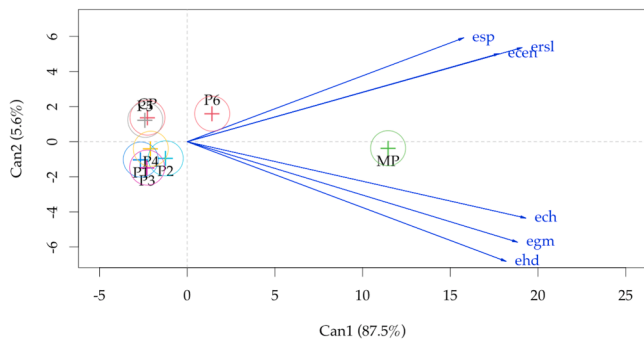
These two methods produce different evaluations, primarily because they are applied to different states of the same product: solid and semi-solid. Nevertheless, both methods effectively distinguish between different patty types, with a slight advantage in discriminatory power observed in the TPAH. Specifically, TPAH captures 98.5 % of the variability across the two axes, while TPA accounts for 93.1 %.



**Fig. 1.** Correlations among parameters measured by the two TPAH and TPA methods: (e)hd = hardness; (e)cen = cohesiveness; (e)gm = gumminess; (e)ch = chewiness; (e)rsl = resilience; (e)sp = springiness.

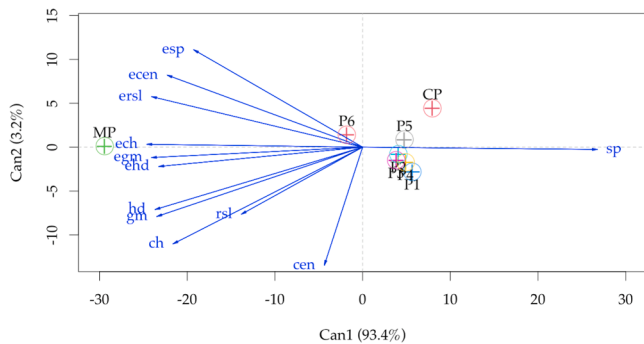


**Fig. 2.** Plot of first two Canonical Variables (CDA) of TPAH parameters measured on cooked homogenized samples. The names of the types of patties are capitalized: MP = meat, CP = commercial, P1 to P6 = homemade pea protein-based patties. In lower case the measured parameters: hd = hardness, cen = cohesiveness, gm = gumminess, ch = chewiness, rsl = resilience, sp = springiness.



**Fig. 3.** Plot of first two Canonical Variables (CDA) of TPA parameters measured on all the types of patties. The names of the types of patties are capitalized: MP = meat, CP = commercial, P1 to P6 = homemade pea protein-based patties. In lower case the measured parameters: ehd = hardness, eceh = cohesiveness, egm = gumminess, ech = chewiness, ersl = resilience, esp = springiness.

A Canonical Discriminating Analysis with all the parameters measured using the two methods could provide further insights into the complementarity between the two methods. Fig. 4 illustrates the distribution of the various types of patties. The distribution, beyond the employed quadrants, resembles that of the TPAH, and the set of TPA variables does not provide additional information. In fact, it explains a lower variability, stopping at 96.6 % on the two axes compared to the



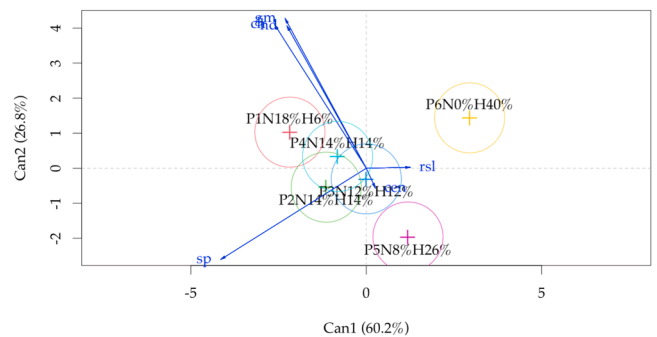
**Fig. 4.** Plot of first two Canonical Variables (CDA) of TPA and TPAH parameters measured on cooked homogenized samples. The names of the types of patties are capitalized: MP = meat, CP = commercial, P1 to P6 = homemade pea protein-based patties. In lower case the measured parameters: (e)hd = hardness, (e)cen = cohesiveness, (e)gm = gumminess, (e)ch = chewiness, (e)rsl = resilience, (e)sp = springiness.

98.5 % of the TPAH alone. This relates to the presence of multi-collinearity among the parameters utilized in CDA. However, both methods offer valuable information, since the patties are consumed as a whole, and the information regarding tenderness is crucial. The TPAH method better describes the contribution of the proteins and fats used in the preparation of patties.

A CDA with the TPAH parameters was applied to the only HPBP, considering the two pea protein ingredients (Ntr, HME) as descriptors of the patties. Fig. 5 illustrates the distribution of the types of patties as a detailed view of Fig. 2 without CP and MP. The TPAH detects the highest presence of the commercial textured pea protein product (Ntr) and the lowest presence of the high moisture extruded pea protein (HME). The explained variability is equal to 87 % on the two axes.

**Discussion**

In our study, the meat and pea protein-based patties were too soft to handle, thus they were homogenized for assessing their texture profile, a crucial aspect for consumers. The hardness indicates the force required to compress a food item between the molars and is defined as the force required to achieve a specific deformation (Novaković and Tomasević, 2017). The research work of Suman and Sharma’s (2003) unveiled a noteworthy finding, indicating a significant rise in shear force values with an increased grind size in meat patties. This observation aligns with McHenry’s (2013) thesis, where she explained how grinder plate size and patty-forming techniques could significantly impact on perceived texture differences in patties. Her study revealed that using smaller grind plates resulted in softer, and more tender patties with smaller particle sizes. In a similar context, Harr et al. (2021) noted that, for shear force, the three ground beef alternatives (retail pea protein-based) were more tender ( $P < 0.05$ ) than all three ground beef treatments. In these studies, a finer grinding process was intended to improve tenderness for consumers, in contrast to this research where homogenization was for analytical purposes. Despite the homogenization of the patty, lower hardness was measured in pea protein-based patties compared to meat patties, aligning with previous research findings. The hardness of meat patties remained largely unchanged (Table 4) and decreased by only 9 %. On the contrary, PBP underwent a significant reduction in hardness following homogenization (TPA = 18.5 N vsTPAH = 9.3 N), representing a 50 % decrease, as detailed in Table 4. This is consistent with the findings of Gurikar et al. (2014), who reported that the hardness value of restructured pork blocks made with larger meat chunks (4–5 cm) was higher than those made with smaller meat chunks (2–3 cm).



**Fig. 5.** Plot of first two Canonical Variables (CDA) for the two-pea protein ingredients according to TPAH parameters measured on cooked homogenized samples. The patties were renamed by adding the % of the two pea protein products (N = Ntr, H = HME). Ntr is a commercial textured pea protein product (70 % of protein) varying between 0 and 18.6 % to improve texture and firmness of patties. HME is a high moisture extruded pea protein product varying between 6.0 and 40.7 %, to improve fibrosity and texture. In lower case the measured parameters: hd = hardness, cen = cohesiveness, gm = gumminess, sp = springiness, ch = chewiness, rsl = resilience.

Additionally, restructured pork blocks made with larger meat chunks exhibited higher gumminess, chewiness, and cohesiveness values. Chandler and McSweeney (2022) observed that the introduction of legume meal reduced the hardness of MP. In another study, the texture profiles of homogenized meat and pea protein-based patties were compared using TPA and it was found that the pea protein-based patties were generally softer and less gummy than the MP (Mabrouki et al., 2023).

In the study conducted by Kamani et al. (2019), the elevated values observed for beef and pork in terms of hardness, chewiness, and gumminess, were more likely due to the presence of myofibril proteins in the meat. The denaturation of the muscle protein contributes to the formation of a more robust internal network, causing higher shrinkage, which, in turn, increases resistance to compression (Ismail et al., 2019; Bakhsh et al., 2021b). In contrast, pea protein-based products exhibited lower values (Kamani et al., 2019). This lattice created by meat proteins maintains its effect on hardness even after homogenization, and it was reduced only by 9 %, highlighting TPAH as a method for assessing the structure of soft products.

Correspondingly, Vu et al. (2022) compared the textural properties of beef and pea protein-based patties cooked using different methods. They revealed that after cooking, the pea protein-based patties had higher water holding capacity after cooking, exhibited less shrinkage, and were softer (lower hardness, cohesiveness, springiness, resilience, and chewiness) than the beef patties.

Regarding cohesiveness, our TPA results showed a significant difference, which was not confirmed by the TPAH, and no correlation was found.

Gumminess is an indication of the energy required to transition a semi-solid food into a ready-to-swallow state and is particularly relevant to foods with low hardness (Novaković and Tomašević, 2017). Our findings reveal that, compared to traditional meat patties (MP), homogenization still resulted in a slight gumminess for all pea protein-based patties. This observation aligns with previous reports indicating that the introduction of non-meat ingredients to meat patties tends to diminish their elasticity (Alesson-Carbonell et al., 2005; Chandler and McSweeney, 2022). Another study employed Texture Profile Analysis to assess the texture properties of meat analogue patties containing both beef and pea protein-based alternatives and concluded that beef patties exhibited higher gumminess values than their pea protein-based counterparts (Bakhsh et al., 2021a). Consistent with our previous publication (Mabrouki et al., 2023), where TPA was employed to compare the texture profiles of homogenized meat and pea protein-based patties, was found that pea protein-based patties generally exhibited lower gumminess compared to traditional meat patties.

Shifting the focus to the chewing force which represents the energy required to chew a solid food to the point where it can be swallowed (Novaković and Tomašević, 2017), and is one of the most crucial properties of patties (Ilic et al., 2023), our findings align with previous research demonstrating that non-meat ingredients can effectively reduce the chewiness of meat products (Godschalk et al., 2022). Likewise, as indicated by Vu et al. (2022), a study replacing pork fat with vegetable oils and utilizing legume proteins from peas, lentils, and other beans can contribute to reduce the chewiness of meat products. The lowest chewiness in PBP was confirmed by both TPA and TPAH methods.

Resilience measures how a sample recovers from deformation in terms of speed and forces. After homogenization, the resilience force increased for the PBP and decreased for the meat patty, while the TPAH was able to significantly identify all the three groups, whereas the TPA was unable to discriminate. There was a significantly positive correlation for resilience, indicating that the recovery to the original height after the initial penetration occurs in the same manner regardless of the physical state. The decrease in resilience values was explained by Hong et al. (2022) using soy protein. The observed lower results in patties made from textured soy proteins could be attributed to the better ability of soy protein to form strong structures, resulting in a more compact

texture and higher bulk density.

The springiness, also known as elasticity, denotes the extent to which a deformed material reverts to its original state after the deforming force is removed (Novaković and Tomašević, 2017). A prior study indicated that meat substitutes made from low-gelling soy isolate protein can hold more water and fat compared to patties made from high-gelling soy isolate protein. This ultimately diminished the springiness of the patties by filling the interstitial space within the protein matrix with water (Youssef and Barbut, 2011). Our findings revealed that PBP exhibited lower springiness than MP, aligning with various studies employing TPA (Alesson-Carbonell et al., 2005; Chandler and McSweeney, 2022). Following homogenization, the springiness of MP decreased while the same parameter of PBP, on average, increased with a negative correlation value. A significant negative correlation for springiness between TPA and TPAH underscores the distinct behaviour of structural changes: solid and semi-solid. Springiness is assessed by the distance of the detected height during the second compression divided by the first compression distance. Homogenization increased the distance/time needed to achieve the second peak, more so for PBP than for MP. According to Bakhsh et al. (2021a), after comparing the TPA of meat analogue patties to beef and pork patties, cohesiveness and springiness varied by patty type, although the difference was not statistically significant.

A plot of CDA representation can be utilized to visually depict the separation between groups in a low-dimensional space. It showcases the canonical scores of each group along the first two or three canonical dimensions, together with the centroids of each group. The canonical structure matrix reveals the correlations between each variable in the model and the discriminant functions.

According to the plots (Figs. 2, 3 and 4), both TPA and TPAH could effectively discriminate between different types of patties. It is crucial to note that the HPBP is prepared by various recipes, which share some components but differ in quantities and preparation methods.

The comprehensive analysis (CDA) of parameters obtained through both TPA and TPAH methods did not exhibit a significant enhancement in the explained variability, as illustrated in Fig. 4. Notably, a clear distinction existed between these parameters when assessing separately TPA and TPAH methodologies, emphasizing their capacity to evaluate distinct facets of the patties, albeit interconnected.

Remarkably, the TPAH method demonstrated an enhanced ability to differentiate between the HPBP, which varied significantly in the quantity of two pea protein products and, in one instance, a variation in the preparation (P4).

Patties labeled as P1 to P4 incorporate less than 14.3 % of a commercial high moisture extrudate pea protein product, while P5 contained 26.4 %, and P6 contains 40.7 %. Another distinguishing factor was the presence of commercial textured pea protein: absent in P6, present at 8.8 % in P5, and ranging from 12.7 % to 18.6 % in types P1 to P4.

In Fig. 5, the TPAH method distinctly revealed its heightened sensitivity in detecting the influence of the two protein products.

## Conclusions

This study compared Texture Profile Analysis applied to different cooked types of patties in the natural state or after homogenization, findings that homogenization of patties could be useful to evaluate texture in soft and coarse products. Notably, homogenization emerges as a pivotal factor, that significantly influences texture characteristics, such as hardness, gumminess, and springiness. The application of TPAH method has proven effective in distinguishing between different patty types, exhibiting marginally enhanced discriminatory capabilities compared to the traditional Texture Profile Analysis. However, both methods provide valuable information, especially when considering that patties are consumed as a whole. The TPAH method better elucidated the contribution of proteins and fats used in patties preparation. These

results hold significant value in comprehending the intricate interplay between processing techniques and patty texture, which is a critical consideration within the realm of the food industry.

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## Ethical statement - Studies in humans and animals

The authors declare that this work did not involve the use of human and animal subjects.

## CRedit authorship contribution statement

**Sabah Mabrouki:** Writing – original draft, Supervision, Formal analysis, Data curation, Conceptualization. **Khalil Abid:** Writing – review & editing, Writing – original draft. **Hatsumi Kaihara:** Writing – review & editing, Writing – original draft. **Sara Glorio Patrucco:** Writing – review & editing, Formal analysis. **Sonia Tassone:** Writing – review & editing, Formal analysis. **Salvatore Barbera:** Writing – review & editing, Writing – original draft, Supervision, Formal analysis, Data curation, Conceptualization.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## Data availability

Data will be made available on request.

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