



Utilization of pea starch and fibre fractions for replacement of wheat crumb in beef burgers

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ABSTRACT

Beef burgers (22% fat) were formulated to contain 5% of pea starch (PS), pea fibre (PF) or their combinations (PS:PF; 75:25, 50:50, 25:75). Wheat crumb treatment served as control. Incorporation of pea fractions into burgers did not affect ($P > .05$) the colour of fresh burgers or the colour stability over 5 days of storage. All burger treatments containing pea fibre had lower ($P < .05$) cook loss than those formulated with wheat crumb or pea starch. Wheat crumb burgers were significantly ($P < .05$) softer, less cohesive and chewy than treatments with pea starch and fibre fractions. While panelist feedback suggest that 50:50 blend resulted in optimal firmness and juiciness characteristics, the acceptability mean scores of all pea starch and pea fibre blends were equivalent to wheat crumb control for all attributes which suggests that all combinations of pea starch and fibre can be utilized as gluten free alternatives to wheat crumb for meat binder applications without any detrimental impact on consumer acceptability.

1. Introduction

Food allergies are estimated to affect nearly 5% of adults and 8% of children, with growing evidence of an increase in prevalence (Sicherer & Sampson, 2014). Since avoidance of food allergens is the only effective means of protecting the health of allergic individuals, Canadian legislation requires mandatory labelling for allergenic food ingredients. Representatives from Health Canada, the Canadian Food Inspection Agency (CFIA), allergy associations and the medical community have identified ten substances (often referred to as the ten priority food allergens) most frequently associated with food allergies and allergic-type reactions. These include eggs, milk, mustard, peanuts, seafood (including fish, crustaceans and molluscs), sulphites, sesame, soy, tree nuts, wheat and other cereal grains containing gluten (Health Canada, 2018).

Non-meat ingredients are used in the manufacture of processed meat products because of their functional properties (e.g., water and fat binding capacity, improvement of texture and appearance among others) (Tarté, 2009; Xiong, 2012). However, some of these (e.g. soy protein, wheat, milk proteins) are classified by health authorities as priority allergens; and thus, their presence in meat products is problematic for many consumers and represents marketing limitations. In addition, the price of raw ingredients is increasing, which has led processors to desire low-cost alternatives that are capable of providing

functionality while minimizing formulation cost. Similarly, there is a growing demand for foods with clean labels and ingredients among the non-allergenic consumer population (gluten-free, non-GMO status). Due to the importance of these ingredients for functionality in processed meats, simply eliminating current binders to produce allergen free products is not a viable option; and as such, alternative strategies are required such as direct substitution with non-allergen options.

Pea is a major protein crop in western Canada. Among the main by-products of its protein extraction process is pea starch, which is widely used for various industrial applications and recently finding increasing usage in the meat industry (Ratnayake, Hoover, & Warkentin, 2002; Zhong et al., 2018). Pea starch is a non-allergen option considered to be relatively cheap compared to starches from corn, wheat or potatoes and could be explored in meat product formulations due to its water/fat binding functionalities as well as its ability to improve product viscosity and textural characteristics. Several studies have explored the positive functional attributes of pea starch in several meat systems (Kilinceker, 2018; Pietrasik & Janz, 2010).

In recent years, increased health consciousness of consumers had led to a shift in mainstream dietary choices including a trend towards meat products with decreased fat content, reduced sodium, lower cholesterol but incorporated with various functional ingredients (Toldra & Reig, 2011). Typically, dietary fibres are added to meat system to hold the increased water content and prevent the impending

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sensory and technological implications (Besbes, Attia, Deroanne, Makni, & Blecker, 2008; Pietrasik & Janz, 2010). Aside from this, dietary fibres has some nutritional as well as economic benefits in meat formulations. The proven functionalities of pea fibre in beef burger (Besbes et al., 2008), low fat bologna (Pietrasik & Janz, 2010), and ground beef (Anderson & Berry, 2001a) have been well documented.

Individual pea fractions, including starch and fibre, have been used as functional ingredients in ground meat products, as texture modifying agents or to support and ensure binding properties of meat proteins. However, no information is available on the combined effect of these ingredients on cooking and textural characteristics of beef burgers. Defining the optimal combination of pea starch and fibre would allow for more efficient and effective use of these ingredients, and enhance our understanding of their functional properties and how they interact in meat systems.

The objective of this study was to evaluate the effectiveness of pea starch and fibre fractions and to determine an optimal pea starch to pea fibre ratio that would allow for replacing a typical wheat crumb in beef burgers. Replacing high priority allergen containing ingredients with non-allergenic alternatives would deliver industry with alternative low cost ingredients that provide product differentiation and address emerging consumer demand for allergen free products.

2. Materials and methods

2.1. Burger treatments and processing

Fresh beef trimmings ($17.13 \pm 0.50\%$ fat, $19.87 \pm 0.03\%$ protein, $63.4 \pm 0.41\%$ moisture) and beef plates ($43.32 \pm 0.68\%$ fat, $12.36 \pm 0.12\%$ protein, and $43.33 \pm 0.55\%$ moisture) were purchased from local processors. Prior to processing, beef trimmings were separately ground through a 4 mm plate (Model AW114, K & G Wetter, Mississauga, ON, Canada). Samples were taken from each batch of ground meat and proximate composition was determined using a Foss FoodScan analyzer (FoodScan Lab, Type 78,800, FOSS, Hillerød, Denmark).

All processing was carried out in a refrigerated pilot plant ($< 7^\circ\text{C}$) at the Food Processing Development Centre (FPDC), Leduc, AB, Canada. Six beef burger treatments (22% fat) were formulated to contain either 5% of pea starch (PS) or pea fibre (PF), or their combinations (75:25, 50:50, 25:75). Toasted commercial wheat crumb (WC, Breader B34216 White #50, Newly Weds Foods Co., Edmonton, AB, Canada) was included at 5% by weight as a control currently used as a binder by the meat industry.

For each treatment, the required quantities of ground beef (81.95%), spices (i.e. 0.8% salt, 0.15% onion powder, 0.1% black pepper), water (12%), and, where required, pea starch/fibre or wheat crumb were combined and mixed at slow speed in a Hobart mixer (A-200 T, Hobart, Trot, OH, USA) for 45 s. The total weight of individual batches was 8 kg. The mixture was then formed into 140 g (5 oz) burger patties using a forming machine (Super 54 Patty machine, Hollymatic, Countryside, IL, USA). Burgers were packaged in cardboard boxes with a plastic liner, frozen and stored for 2 weeks at -20°C until evaluation.

2.2. Instrumental evaluation

2.2.1. Colour and oxidative stability

After forming, three burgers from each treatment were packaged individually on Styrofoam® trays over-wrapped with an O₂-permeable film ($8000\text{ cm}^3/\text{m}^2/24\text{ h}$; Vitafilm, Huntsman Film Products of Canada, Toronto, ON, Canada). The packaged burgers were then placed in a two tier display deck cabinet (MPM-72, Master-Bilt® Refrigeration Solutions, Albany, MS, USA) maintained at $4.0 \pm 1^\circ\text{C}$ under 24 h fluorescent lighting with an average light intensity of 1630 lx (CRI = 85) for instrumental colour evaluation over a 5-day period.

2.2.1.1. Instrumental colour evaluation. Surface colour of burgers was measured objectively using a Minolta handheld spectrophotometer (Minolta CM-2500C, Osaka, Japan) with a 10° observer angle, 8 mm aperture and illuminant A, and calibrated against a white tile immediately before readings were taken. Colour measurements (CIE L^* , a^* , and b^*) were taken at day 0, and after 1, 2, 3, 4 and 5 days of retail display under aerobic conditions. The L^* , a^* , b^* values for each burger were reported as the average of four readings. Additionally, hue angle was calculated as: $\tan^{-1}(b^*/a^*)$, the saturation index (chroma) calculated as: $(a^{*2} + b^{*2})^{0.5}$.

2.2.1.2. 2-Thiobarbituric acid reactive substances (TBARS) test. TBARS measurements were done in triplicate on fresh burgers and on raw burgers stored at -20°C for 4 months as previously described by Nam and Ahn (2002). A sample (3 g) was placed in a 50 mL disposable centrifuge tube and homogenized with 15 mL deionized distilled water and 50 μL butylated hydroxytoluene (7.2%) using a Brinkman Polytron (Type PT 10/35; Brinkman Instrument Inc., Westbury, NY, USA.) for 15 s at velocity setting 7. The meat homogenate (1 mL) was transferred to a disposable test tube (15 mL), and 2 mL 2-thiobarbituric acid/trichloroacetic acid (20 mM TBA and 15% [w/v] TCA) solution was added. The mixture was vortexed for 10 s and then incubated in a 90°C water bath for 15 min to develop colour. After cooling for 10 min in cold water, the samples were vortexed and centrifuged at $3000 \times g$ for 15 min. The absorbance of the resulting supernatant was read at 531 nm against a blank prepared with 1 mL deionized water and 2 mL TBA/TCA solution using a UV-Vis spectrophotometer (Agilent 8453, Agilent Technologies Canada Inc.). TBARS were calculated from a 1,1,3,3-tetraethoxypropane standard curve.

2.2.2. Evaluation of burgers after frozen storage:

2.2.2.1. Cooking measurements. Frozen burgers (10 per treatment per replication) were cooked on an electric grill (Garland ED-42B electric broiler, Russell Food Equipment Ltd., Edmonton, AB, Canada) preheated to 190°C . The burgers were placed on the grill, turned over every 3 min, and cooked until the internal temperature reached 71°C . The burgers were allowed to cool for 5 min at room temperature and weighed. Cooking loss was calculated based on initial frozen burger weight. Diameter of each burger was measured with a ruler across the raw and cooked burger in two directions at 90° angle to each other. The dimensional changes were calculated based on initial frozen burger diameter.

2.2.2.2. Proximate analysis and pH. Proximate analysis (total moisture, protein and fat) measurements were performed in triplicate using an AOAC-approved (official method 2007.04; Anderson, 2007) near infrared spectrophotometer (FoodScan Lab, Type 78800, FOSS, Hillerød, Denmark). The pH of cooked products was measured in duplicate with a pH meter (Hanna Instruments FC240, Canadawide Scientific, Ottawa, ON, Canada) on a homogenate of 20 g sample in 80 mL deionized water.

2.2.2.3. Moisture and fat retention determination. Moisture and fat retention values of burgers after cooking, were calculated as follows:

Moisture retention (%)

$$= \left[\frac{(\text{cooked weight} \times \% \text{moisture in cooked burger})}{(\text{raw weight} \times \% \text{moisture in raw burger})} \right] \times 100\%$$

Fat retention (%)

$$= \left[\frac{(\text{cooked weight} \times \% \text{fat in cooked burger})}{[(\text{raw weight} \times \% \text{fat raw burger})]} \right] \times 100\%$$

2.2.2.4. Expressible moisture (EM). Expressible moisture was

determined by a modified method as described by Pietrasik and Shand (2004). Briefly, three cylindrical meat cores (10 mm diameter x 15 mm length) of known weight (3.0 ± 0.5 g) were cut and placed in 50 mL centrifuge tubes fitted with a thimble consisting of two Whatman No. 3 filter papers folded around a Whatman No. 50 filter paper, centrifuged (Rotor #11457, MPW Med. Instruments, Warsaw, Poland) at $963 \times g$ for 10 min and then reweighed. EM was expressed as the ratio of the weight lost after centrifugation to the initial sample weight.

2.2.3. Textural properties

2.2.3.1. Texture profile analysis (TPA). The textural properties of cooked beef burgers were determined according to texture profile analysis (TPA) (Bourne, 1982) using an Instron texture system (Model 5565, Instron Corporation, Burlington, ON, Canada). Three core samples (22 mm diameter) were cut from the center of two burgers per treatment (6 samples per treatment per replication) and compressed twice to 30% of their original height with a 9 cm flat ended steel plunger at a constant cross-head speed of 60 mm/min. The TPA parameters, namely hardness (peak force on first compression [N]), cohesiveness (ratio of the active work done under the second force-displacement curve to that done under the first compression curve [dimensionless]), springiness (distance the sample recovered after the first compression [mm]), and chewiness (hardness x cohesiveness x springiness [N*mm]) were computed.

2.2.3.2. Shear force. Shear force analysis of cooked beef burgers was determined for each treatment using an Instron texture system (Model 5565, Instron Corporation, Burlington, ON, Canada). Burgers were cooked as described previously, and allowed to cool for 1 h at room temperature. Then, a 2.5 cm wide strip was cut from the center of each burger, ensuring that burger edges were excluded. Prepared samples (3 per treatment per replication) were sheared with a straight-edge blade fixture at three sample locations using a crosshead speed of 250 mm/min. Shear force was expressed in Newtons (N).

2.2.3.3. Bind strength. The bind force (maximum load supported by a sample before tearing) of five cooked burgers was determined for each treatment using an Instron Universal Testing System (Model 5565, Instron Corporation, Burlington, ON, Canada). Samples were secured with a set of needles on the test cell platform and the platform was pulled apart at a crosshead speed of 100 mm/min to just beyond the point of rupture of the beef burger. Bind strength was reported as maximum peak force (N) recorded during the test required to rupture a sample.

2.2.4. Consumer acceptability

One hundred and twenty two consumers (48% female and 52% male, 18–65 yrs.) were recruited from Edmonton, Alberta following adequate screening for eligibility that they are regular consumers of beef burgers. Burgers were first cooked to an internal temperature of 71 °C flipping every 3 min until reaching the target internal temperature. A cook chart randomized the placement of burgers on the electric grill. Individual cooked burgers were cut into 1/3 wedge shaped pieces, wrapped in foil, and held at 60 °C in an environmental chamber until served to consumers. Data were collected using *Compusense Cloud* software.

Using a fully randomized block design, samples were presented to consumers monadically to evaluate overall acceptability as well as consumers' liking of appearance, flavour, texture and aftertaste on a 9-point hedonic scale (1 = dislike extremely, 2 = dislike very much, 3 = dislike moderately, 4 = dislike slightly, 5 = neither like nor dislike, 6 = like slightly, 7 = like moderately, 8 = like very much, 9 = like extremely). Following hedonic questions for flavour and texture, 7-point *Just About Right* (JAR) scales were used to gain insight into perceived levels of beef flavour, firmness and juiciness (1 = too weak/too soft/too dry, 4 = Just About Right, 7 = too strong/too firm/too

juicy). After JAR scaling, *Check All That Apply* (CATA) terms were presented to obtain a deeper insight into the consumer perception of flavour (terms = grilled, chalky, starchy, bitter, metallic, off-flavour, tangy/sour, bland, sweet, spices/seasoning, salty) and texture (terms = rubbery bite, tough/leathery, granular/gritty, chalky, crumbly, mushy/pasty, greasy/oily mouthcoat, chewy) across all treatments. Consumers' purchase intent was also evaluated using a 5-point scale (1 = definitely would not purchase, 2 = would not purchase, 3 = might/might not purchase, 4 = would purchase, 5 = definitely would purchase). To avoid carryover effect (Lawless & Heymann, 1998), a 90 s break was enforced between samples during which panelists cleansed their palate using unsalted crackers and room temperature water.

2.3. Data analysis

Three processing replications were completed. Processing and instrumental data were subject to analysis of variance using the PROC MIXED procedure of SAS (v. 9.1.3, SAS Institute Inc., Cary, NC). The model included fixed effect of treatment and random effect of processing replication. For colour stability data, a retail display day was included as a repeated measure in the model via the REPEATED option. For consumer panel data, XLSTAT (v.XLSTAT 2019.1.3.58109) was used for data analysis. Evaluation day and panelists were listed as random factors. For all analyses, least-squares means were calculated for all main effects or interactions and the means were separated using the probability of difference option with a Tukey adjustment when the respective F-tests were significant ($P \leq .05$). Frequencies of purchase intent scores were calculated. CATA frequency data was summarized in a contingency table and subjected to Correspondence Analysis using chi-square-distances (Vidal, Tarrega, Antunez, Ares, & Jaeger, 2015). Principal Coordinate Analysis was conducted on the correlation matrix of CATA descriptor frequencies and overall acceptability scores. JAR results were subjected to Penalty Analysis with statistical significance at $P < .05$. Penalties for JAR attributes rated as above or below 'Just About Right' were calculated and mean results for acceptability scores were adjusted accordingly.

3. Results and discussion

3.1. Instrumental colour evaluation

Addition of pea ingredients had a minimal effect on colour. Instrumental colour measurements showed that there was no significant ($P > .05$) effect of treatment on instrumental colour of a^* , b^* , saturation index and hue angle parameters (Table 1). Beef burgers incorporated with pea fibre were significantly ($P < .05$) darker in colour than wheat crumb treatments and those processed with blends containing $> 25\%$ of pea starch. It was evident that an increase in proportion of added starch favoured the appearance of a lighter colour; however, the magnitude of difference was small and would normally be considered to be of little or no practical importance to consumer purchasing intent. In agreement with our results, others have reported an increased lightness of burgers or meatballs incorporated with starch-rich legume flours (Dzudie, Scher, & Hardy, 2002; Serdaroglu, Yildiz-Turp, & Abrodímov, 2005).

The change in colour of fresh burgers was monitored over 5 days of simulated retail display. As aerobic display time increased, there was a decline in a^* , b^* and Chroma (saturation index) and an increase in hue angle values, while L^* remained constant throughout the whole display time (Table 1). No significant interaction between treatments and retail display time was observed for any of the colour parameters, indicating that incorporation of pea starch and fibre at ratios tested in this study does not compromise colour stability of beef burgers during retail display. The pattern of changes in colour of beef burgers is consistent with previous studies documenting colour change in ground beef during

Table 1

Effect of pea starch and pea fibre combinations on colour stability of beef burgers during retail display.

Effect	L*	a*	b*	Chroma	Hue angle
Treatments ¹					
WC	51.9 ^a	18.7	19.9	27.5	47.6
PS	52.6 ^a	19.1	20.6	28.3	48.1
PS75:PF25	52.6 ^a	18.4	20.3	27.5	48.6
PS50:PF50	52.0 ^a	18.8	20.5	27.9	48.3
PS25:PF75	51.3 ^{ab}	18.4	19.9	27.2	48.1
PF	50.6 ^b	19.0	20.2	27.8	47.7
SEM ²	0.46	0.74	0.33	0.74	0.73
P-value	< 0.01	0.84	0.08	0.61	0.86
Retail display time, days					
0	52.5	25.2 ^a	23.2 ^a	34.3 ^a	42.6 ^d
1	51.6	22.3 ^b	21.5 ^b	31.0 ^b	44.1 ^{cd}
2	51.5	19.8 ^c	20.5 ^c	28.5 ^c	46.1 ^c
3	52.0	16.7 ^d	19.4 ^d	25.7 ^d	50.0 ^b
4	51.8	15.1 ^{de}	18.9 ^d	24.3 ^d	51.9 ^{ab}
5	51.7	13.3 ^e	17.9 ^e	22.3 ^e	53.7 ^a
SEM	0.46	0.74	0.33	0.74	0.73
P-value	0.31	< 0.01	< 0.01	< 0.01	< 0.01
Treatments x Retail display time interaction					
SEM	0.87	1.27	0.56	1.22	1.50
P-value	0.99	0.99	0.97	0.99	0.99

^{a-e}Means with different letters in the same column within each fixed effect are significantly different ($P < .05$).

¹ Treatments: WC, wheat crumb, PS, pea starch, PS75:PF25, PS50:PF50, PS25:PF75 pea starch to pea fibre percentage ratio in the binder blend, PF, pea fibre.

² SEM, standard error of the means.

retail display in traditional overwrap packages (Garner, Unruh, Hunt, Boyle, & Houser, 2014; Martin et al., 2013; Troutt et al., 1992).

3.2. TBARS test

There was increase in rancidity of raw burgers from initial values of 0.9–1.2 to 1.6–1.8 mg malonaldehyde/kg sample during 4 month frozen storage. However, formulation treatment had no significant ($P > .05$) effect on the oxidative stability of raw beef burgers during frozen storage suggesting that treatments processed with pea fractions were comparable to WC in development of lipid oxidation over time. No effect on oxidative stability of buffalo or beef burgers meats incorporated with legume based binders has also been reported by other authors (Der, 2010; Modi, Mahendrakar, Rao, & Sachindra, 2004). Serdaroğlu et al. (2005) reported lower TBARS values after frozen storage of beef meat balls processed with blackeye bean flour and chickpea flour as compared to the rusk treatment. On the other hand, some authors observed an increased lipid oxidation in breakfast sausages incorporated with 2.5% pea flour (Purohit, Reed, & Mohan, 2016) or 30% of chickpea flour (Verma, Ledward, & Lawrie, 1984).

3.3. Proximate composition and pH

There were no significant differences ($P > .05$) in proximate composition among the burger treatments. The composition of raw beef burgers ranged from 57.5 to 58.7% moisture, 16.1 to 16.4% protein and 22.4 to 23.2% fat (data not shown). In comparison with raw burgers, cooking of burgers to 71 °C resulted in an increase of protein content at the expense of reduced fat and moisture. Similarly to raw burgers, treatment had no effect on amount of protein and moisture in cooked burgers. Protein and moisture content varied from 23.1 to 24.1% and 51.3 to 51.8%, respectively. Different ratios of pea fibre and starch significantly ($P < .05$) affected fat content which was the lowest in burgers processed with wheat crumb and tended to increase with increased incorporation of pea fibre to burger formulations. The pH

Table 2

Cooking characteristics of beef burgers.

Treatments ¹	Cook loss (%)	Diameter shrinkage (%)	Thickness shrinkage (%)	Fat retention (%)	Moisture retention (%)
WC	32.5 ^a	15.1 ^{ab}	16.2	58.3 ^c	60.2
PS	33.5 ^a	15.9 ^a	16.2	61.9 ^{bc}	58.8
PS75:PF25	30.3 ^b	14.8 ^{bc}	18.9	62.4 ^{bc}	61.5
PS50:PF50	30.0 ^b	12.6 ^d	16.0	63.9 ^{ab}	62.5
PS25:PF75	30.1 ^b	13.3 ^d	16.9	65.3 ^{ab}	62.4
PF	30.4 ^b	13.6 ^{cd}	15.8	68.5 ^a	61.5
SEM ²	0.63	0.55	1.43	1.66	1.14
P-value	< 0.01	< 0.01	0.06	< 0.01	0.06

^{a-d}Means with different letters in the same column are significantly different ($P < .05$).

¹ Treatments: WC, wheat crumb, PS, pea starch, PS75:PF25, PS50:PF50, PS25:PF75 pea starch to pea fibre percentage ratio in the binder blend, PF, pea fibre.

² SEM, standard error of the means.

values of the cooked burgers were consistent across all formulations and ranged from 6.41 to 6.49.

3.4. Cooking characteristics of beef burgers

Water and fat retention are important functional characteristics of ground beef burgers. Ability to retain moisture and fat, in addition to positively affecting cook yield, prevents excessive shrinkage and is important in maintaining desirable juiciness, texture and flavour; thus, assuring adequate palatability of cooked products. The cooking loss of beef burgers incorporated with pea fibre or blends of pea fibre with pea starch was significantly lower compared to control wheat crumb burgers (Table 2). All burger treatments containing pea fibre had lower ($P < .05$) cook loss than those formulated with wheat crumb or pea starch.

The amount of liquid lost during thermal processing of meat products is mostly associated with fat and water retention (Aleson-Carbonell, Fernández-López, Pérez-Alvarez, & Kuri, 2005) and is usually related to the ability of the protein matrix to retain water and fat (Rocha-Garza & Zayas, 1996). In addition, in a burger system, non-meat ingredients (mainly carbohydrate-rich ingredients such as cereal flours, plant fibres or starch) are used extensively as fillers, binders and extenders to support muscle proteins by creating meat matrices with enhanced texture and water and fat holding capabilities (Tarté, 2009; Xiong, 2012).

Lower cook loss in burgers containing pea fibre was likely due to its increased ability to keep moisture and fat in the matrix compared to WC control. Anderson and Berry (2001b) evaluated different starch-, fibre- and protein-based ingredients for their fat holding capacity in 20% fat ground beef. They found that high fibre ingredients had significantly higher fat holding capacity than other ingredients, with inner pea fibre and cellulose being more effective fat binders than sugar beet and oat fibres. In agreement with these authors, our study showed that the burgers processed with pea fibre had significantly greater ($P < .05$) fat retention than WC control. There was almost a linear increase in the amount fat retained after cooking with the increased proportion of pea fibre in the binder blend. PF burgers also had a tendency ($P = .05$) to retain more water after cooking as compared to burgers incorporated with pea starch.

Decreased cooking loss due to an ability to hold moisture and fat in the meat matrix by dietary fibres have been reported using different sources, including passion fruit albedo (López-Vargas, Fernández-López, Pérez-Alvarez, & Viuda-Martos, 2014), hazelnut pellicle (Turhan, Sagir, & Ustun, 2005), tiger nut fibre (Sanchez-Zapata et al., 2009), lemon albedo fibres (Aleson-Carbonell et al., 2005) and pea and wheat fibres (Besbes et al., 2008; Mansour & Khalil, 1997).

Table 3
Instrumental textural properties of beef burgers.

Treatments ¹	Hardness (N)	Cohesiveness	Springiness (mm)	Chewiness (N*mm)	Shear force (N)	Bind strength (N)
WC	124.9 ^c	0.25 ^d	6.1 ^b	193.6 ^c	25.9	23.8 ^{ab}
PS	169.4 ^b	0.29 ^c	6.9 ^a	341.9 ^b	30.0	26.6 ^a
PS75:PF25	170.4 ^b	0.30 ^{bc}	6.9 ^a	356.9 ^b	28.7	23.7 ^{ab}
PS50:PF50	183.8 ^b	0.31 ^b	6.5 ^a	370.2 ^b	29.4	20.9 ^{bc}
PS25:PF75	185.9 ^b	0.32 ^b	6.6 ^a	385.5 ^b	28.3	20.5 ^{bc}
PF	207.3 ^a	0.33 ^a	6.7 ^a	460.6 ^a	29.4	18.2 ^c
SEM ²	6.54	0.01	0.14	18.0	2.1	1.45
P-value	< 0.01	< 0.01	< 0.01	< 0.01	0.16	< 0.01

^{a-c}Means with different letters in the same column are significantly different ($P < .05$).

¹ Treatments: WC, wheat crumb, PS, pea starch, PS75:PF25, PS50:PF50, PS25:PF75 pea starch to pea fibre percentage ratio in the binder blend, PF, pea fibre.

² SEM, standard error of the means.

Table 4
Mean scores from consumer sensory panel assessments for beef burgers (n = 122) using a 9-point hedonic scale¹.

Treatment ²	Overall Acceptability	Appearance	Flavour	Texture	Aftertaste
WC	6.47 ^a	6.46 ^{ab}	6.38 ^a	5.91 ^{ab}	6.03 ^a
PS	6.11 ^a	6.32 ^{ab}	6.14 ^a	5.57 ^b	5.60 ^{ab}
PS75:PF25	6.48 ^a	6.42 ^{ab}	6.51 ^a	5.95 ^{ab}	5.98 ^a
PS50:PF50	6.40 ^a	6.64 ^a	6.39 ^a	6.29 ^a	6.02 ^a
PS25:PF75	6.36 ^a	6.48 ^{ab}	6.11 ^a	5.70 ^{ab}	5.75 ^{ab}
PF	5.35 ^b	5.91 ^b	5.31 ^b	4.60 ^c	5.19 ^b
SEM ³	0.17	0.16	0.17	0.18	0.16
P-value	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001

^{a-c}Means with different letters in the same column are significantly different (HSD; $P < .05$).

¹ Scored on 9-point hedonic scales where 1 = dislike extremely, 2 = dislike very much, 3 = dislike moderately, 4 = dislike slightly, 5 = neither like nor dislike, 6 = like slightly, 7 = like moderately, 8 = like very much, 9 = like extremely.

² Treatments: WC, wheat crumb, PS, pea starch, PS75:PF25, PS50:PF50, PS25:PF75 pea starch to pea fibre percentage ratio in the binder blend, PF, pea fibre.

³ SEM, standard error of the means.

Shariati-Ievari et al. (2016) reported lower cooking loss from burgers containing 6% chickpea or green lentil as compared to control. They postulated that the ability of chickpea and lentil to retain fat and moisture in cooked low-fat beef burgers was due to dietary fibre present

in pulse flours. Dzudie et al. (2002) showed a significant decrease in cooking loss of beef sausages extended by 5, 7.5, and 10% common bean flour (CBF) compared to control with no CBF.

Anderson and Berry (2000) found that when low levels (1.6%) of pea fibre were added to 10 and 14% fat ground beef patties, cooking yield increased but fat retention did not change compared to all-beef patties. However, the same authors reported that addition of pea fibre at a usage level of at least 10% significantly increased both fat retention and cooking yield in high fat ground beef (Anderson & Berry, 2001a). They hypothesized that the mechanism for increases in fat retention was predominantly physical in nature and postulated that, in addition to fat absorption by the fibre, swelling of the starch and fibre may have interacted with the muscle proteins to form a matrix, which prevented the coalescence and migration of fat out of the product.

Fat and water retention properties of plant insoluble dietary fibres are mostly related to the size and structure of their main components - cellulose, hemicellulose, and pectin (de Almeida Costa, da Silva Queiroz-Monici, Reis, & de Oliveira, 2006; Heredia, Jiménez, & Guillén, 1995). The cellulose in pulses is organized in a series of hydrogen bonded linear polymers forming into microfibrils. Longer length cellulose fibres were reported to have better fat retention capacity than cellulose with shorter fibre lengths (Ang, 1991). Also, by connecting to interlinked hemicellulose, cellulose forms inter spaces and increases surface area of fibre structure which contributes to the water and oil holding capacity of insoluble fibres (Heredia et al., 1995).

During cooking, denaturation of meat protein causes release of water and fat trapped inside the meat matrix and as a result this loss of water and fat leads to shrinkage of the burgers.

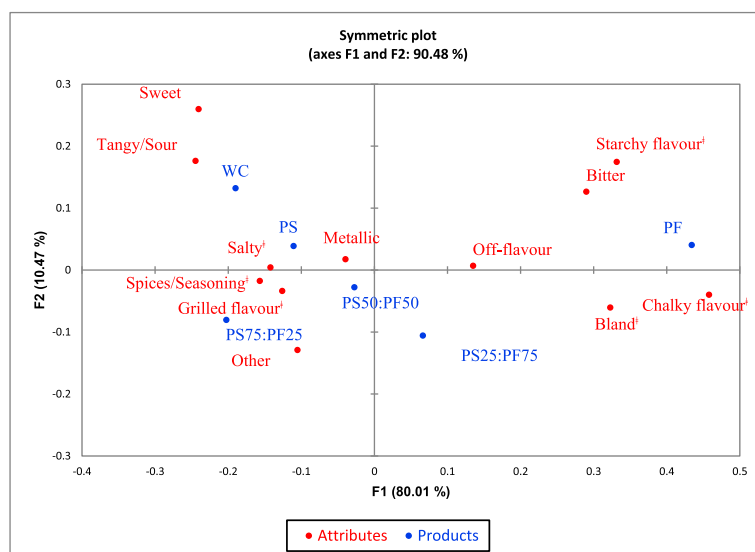


Fig. 1. CATA analysis for beef burger flavour attributes as selected by consumers (n = 122). Treatments: WC, wheat crumb, PS, pea starch, PS75:PF25, PS50:PF50, PS25:PF75 pea starch to pea fibre percentage ratio in the binder blend, PF, pea fibre. † Attributes significantly different at $P < .05$, other attributes are not significantly different between treatments.

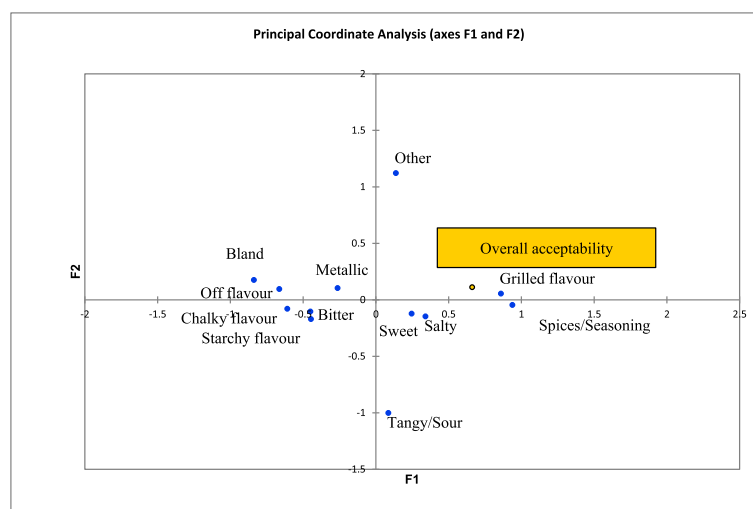


Fig. 2. Principal coordinate analysis for flavour attributes relative to overall acceptability for beef burgers.

In our study, blends containing > 50% of PF resulted in smaller dimensional shrinkage compared to WC and PS burgers. Lower shrinkage in burgers processed with blends containing a higher proportion of pea fibre was likely associated with higher moisture and fat retention capacity of fibre as compared to pea starch or wheat crumb.

In agreement with our results, Besbes et al. (2008) observed a smaller reduction in diameter of beef burgers with addition of pea and wheat fibres. Anderson and Berry (2000) reported that beef patties processed with 1.6% addition of pea fibre showed less change in thickness during cooking with no effect on diameter shrinkage compared to all-beef controls. A lower dimensional shrinkage as a result of incorporation of different dietary fibres was also reported in beef burgers containing oat fibre (Desmond, Troy, & Buckley, 1998a) or lemon albedo fibres (Aleson-Carbonell et al., 2005), low-fat beef burgers incorporated with hazelnut pellicle (Turhan et al., 2005) or pork burgers added with albedo-fibre powder (López-Vargas et al., 2014) or tiger nut fibre (Sánchez-Zapata et al., 2010).

Cooking characteristics of burgers incorporated with pea starch were equivalent to the products processed with wheat crumb. Various starches have been shown to be effective binders in different meat systems; however, very limited research has been conducted on evaluation of pea starch in ground meats. Kilincceker (2018) evaluated addition of up to 5% of potato, corn or pea starches and found that 5% level of pea starch was the most effective as a binder in fried meat patties. Tabarestani and Tehrani (2014) also reported that 5% level of wheat starch was optimum for cooking yield and other properties of low-fat hamburger formulation. Moreover, Anderson and Berry (2001b) found that pea starch had better fat absorbing ability than water absorption compared to potato starch. Wan Rosli, Nurhanan, Solihah, and Mohsin (2011) evaluated different ratios of potato starch and cornsilk fibre in beef patties and found, in agreement with our study, that increased proportion of fibre was effective in improving cooking yield, moisture and fat retention.

3.5. Textural characteristics of beef burgers

Texture is one of the most important sensory attributes of ground meat products. The textural properties of cooked burgers refer to evenness, consistency, and uniformity, as well binding of meat particles together as well as elasticity and hardness of the final product (Coggins, 2012). Wheat crumb burgers were significantly ($P < .05$) softer, less cohesive and less chewy than treatments incorporated with pea starch and fibre fractions (Table 3). There was a trend for an increase in burgers firmness with increasing addition of pea fibre. Disparate results

have been reported on the effect of dietary fibre addition on textural characteristics of meat products depending on the amount and type of fibre used. Both hardening and softening effects have been observed when high dietary fibre fractions were incorporated into formulations of different meat products (Ganhão, Morcuende, & Estévez, 2010; García, Cáceres, & Selgas, 2007; Sánchez-Zapata et al., 2010; Viuda-Martos, Ruiz-Navajas, Fernández-López, & Pérez-Álvarez, 2010).

López-Vargas et al. (2014) in agreement with the present results reported that addition of 2.5 or 5% passion fruit albedo, high in dietary fibre, led to an increase in hardness ($P < .05$) of pork burgers. Serdaroglu et al. (2005) reported that meat balls with the addition of legume flours were tougher as compared to those formulated with rusk and postulated that the swelling of the starch component in rusk may have interacted with muscle proteins to form a softer texture.

Sánchez-Zapata et al. (2010) and Aleson-Carbonell et al. (2005) indicated that the hardness was not affected by the addition of increasing amounts of tiger nut fibre or lemon albedo in pork and beef burgers, respectively. Also, Yilmaz (2004) did not observe any effect on firmness of low-fat meatballs incorporated with up to 15% of rye bran.

On the other hand, Verma, Banerjee, and Sharma (2015) observed a decreased hardness with increased addition of pea hull flour to low fat low salt chicken nuggets. They suggested that pea hulled flour could have interfered in the formation of a uniform and stable meat matrix and led to lower hardness. Burgers formulated with increased proportion of pea starch in binder blend had increasingly higher bind; whereas the bind was the lowest in burgers processed with addition of pea fibre alone. To our knowledge, there are no studies examining the effect of varying ratios of pea starch or fibre on the textural characteristics of beef burgers. In most cases, the influence of specific amounts or other types of starches have been analysed. Troutt et al. (1992) reported that potato starch, in combination with polydextrose and plant fibre ingredients in low-fat beef burgers, reduced peak load and total energy as compared to 5 and 10% fat control beef burgers. Desmond, Troy, and Buckley (1998b) examined combined effect of tapioca starch and oat fibre on textural properties of beef burgers and found that burgers containing these ingredients required less force and energy to shear the samples.

In our study, no significant effect ($P > .05$) of formulation treatment on shear force was found. Anderson and Berry (2000) observed a decrease in shear force of 10% fat beef patties incorporated with 1.6% dry pea fibre as compared with all-beef controls. Similarly, Troutt et al. (1992) and Troy, Desmond, and Buckley (1999) reported a decreased shear force in low-fat beef patties with addition of sugar beet fibre and tapioca starch while addition of oat fibre and bran resulted in lower

Table 5
Just about right (JAR) and penalty analysis for beef burger attributes.

Levels	WC			PS			PS75:PF25			PS50:PF50			PS25:PF75			PF		
	Selection % ^a	Mean OA ^b	Mean OA	Selection %	Mean OA	Mean OA	Selection %	Mean OA	Mean OA	Selection %	Mean OA	Mean OA	Selection %	Mean OA	Mean OA	Selection %	Mean OA	Mean OA
Beef flavour	30.3	5.41 ^c	5.49 ^c	36.9	5.49 ^c	5.85 ^c	33.6	5.85 ^c	5.26 ^c	31.2	5.26 ^c	5.05 ^c	36.1	5.05 ^c	5.05 ^c	60.7	4.55 ^c	4.55 ^c
JAR	50.0	7.03	6.76	45.1	6.76	7.39	44.3	7.39	7.46	48.4	7.46	7.32	45.9	7.32	7.32	25.4	6.87	6.87
Too strong	19.7	6.67	5.77	18.0	5.77	5.63 ^c	22.1	5.63 ^c	5.64 ^c	20.5	5.64 ^c	6.55	18.0	6.55	6.55	13.9	6.06	6.06
Overall penalty	1.13 ^c			1.18 ^c			1.62 ^c			2.05 ^c			1.78 ^c			2.04 ^c		
Firmness	37.7	5.61 ^c	5.31 ^c	32.0	5.31 ^c	6.03 ^c	25.4	6.03 ^c	5.12 ^c	21.3	5.12 ^c	5.77 ^d	27.9	5.77 ^d	5.77 ^d	24.6	5.10 ^d	5.10 ^d
JAR	49.2	7.18	6.89	42.6	6.89	7.07	49.2	7.07	6.92	58.2	6.92	7.00	44.3	7.00	7.00	30.3	6.65	6.65
Too firm	13.1	6.25	5.85 ^c	25.4	5.85 ^c	5.81 ^d	25.4	5.81 ^d	6.28	20.5	6.28	5.94 ^d	27.9	5.94 ^d	5.94 ^d	45.1	4.62 ^c	4.62 ^c
Overall penalty	1.41 ^c			1.34 ^c			1.15 ^c			1.23 ^c			1.15 ^c			1.86 ^c		
Juiciness	15.6	6.00	5.59 ^d	22.1	5.59 ^d	6.00 ^e	27.87	6.00 ^e	5.54 ^c	23.0	5.54 ^c	5.94 ^d	39.3	5.94 ^d	5.94 ^d	59.8	4.86 ^c	4.86 ^c
JAR	50.8	7.13	6.74	47.5	6.74	6.89	45.9	6.89	7.17	52.5	7.17	6.96	44.3	6.96	6.96	23.8	6.72	6.72
Too juicy	33.6	5.68 ^c	5.51 ^d	30.3	5.51 ^d	6.28	26.2	6.28	5.57 ^c	24.6	5.57 ^c	5.75	16.4	5.75	5.75	16.4	5.15	5.15
Overall penalty	1.35 ^c			1.20 ^c			0.76 ^c			1.62 ^c			1.08 ^d			1.80 ^c		

Treatments: WC, wheat crumb, PS, pea starch, PS75:PF25, PS50:PF50, PS25:PF75 pea starch to pea fibre percentage ratio in the binder blend, PF, pea fibre.

^a Selection %. The percentage of consumers corresponding to the different collapsed JAR levels.

^b Mean OA; Mean Overall Acceptability corresponding to each JAR levels.

^c Mean drop with level of significance < 0.001.

^d Mean drop with level of significance between 0.001 and 0.01.

^e Mean drop with level of significance > 0.01.

peak load but higher peak energy in 10% fat patties (Berry, 1992).

3.6. Consumer acceptability of beef burgers

Consumers' overall acceptability for all burger treatment combinations were not significantly different from the wheat crumb control with the exception of 100% PF which was significantly less preferred compared to all other burger treatments ($P < .001$, Table 4). Similarly, while other treatments had comparable liking scores for flavour, aftertaste and texture compared with control, 100% PF burger had the lowest liking score for all respective attributes. Generally, the inclusion of PS or PF did not significantly affect the appearance acceptability of beef burgers. From our findings, we demonstrate that the addition of pea fibre up to about 75% did not result in decrease in the consumer acceptability of grilled beef burger when compared to WC control. While 100% pea fibre had a detrimental impact on the product's overall, flavour, and texture consumer acceptance compared to control, 100% pea starch was not significantly different from the control. This is similar to previous findings in corn beef (Pietrasik, Pierce, & Janz, 2012), fried meat patties (Kilincceker, 2018) and low fat bologna (Pietrasik & Janz, 2010; Sanjeewa, Wanasundara, Pietrasik, & Shand, 2010) where the addition of pea starches did not significantly impact the consumer acceptability of meat products.

Other studies have demonstrated that consumer acceptability of meat products decrease as fibre content increases particularly, above 3% (Biswas, Kumar, Bhosle, Sahoo, & Chatli, 2011; Eim, Simal, Rosselló, & Femenia, 2008; Talukder, 2015). The work presented here supports this finding, where an increasing addition of pea fibre resulted in a corresponding higher frequency of consumers' usage of the term "bland" to describe beef burgers (Data not shown). The association of higher level of PF inclusion in beef burger formulation with bland, chalky and starchy flavour was also evident with CATA analysis (Fig. 1). Overall, the attributes that consumers associated with high overall acceptability and as such, of high liking impact for these beef burgers are grilled flavour, spices/seasoning flavour and saltiness (Fig. 2). All samples except those of high PF inclusion, are associated with these liking attributes (Fig. 1). According to JAR analysis, beef flavour, firmness and juiciness are important attributes contributing to consumer flavour liking of burgers and could result in consumers penalizing the products (Table 5). Inclusion of 100% PF resulted in burgers being more severely penalized compared to those with a lesser inclusion level. This was shown particularly for beef flavour as "too weak", where 61% of consumers and 2.3 mean drop occurred. Similarly, with increasing pea fibre content in beef burgers, there was a corresponding increase in the use of CATA texture terms such as "crumbly", "granular/gritty", "starchy mouth-coating" and "chalky" to describe the burgers (Fig. 3). In fact, through JAR scaling, high percentages of panelists described PF burgers as "way to dry" (60%) and "way too firm" (45%). A decrease in the consumer acceptability, especially with high inclusion of fibre, also resulted in decreased consumers' willingness to purchase this product compared to other treatments (Data not shown). As such, although fibre inclusion may have some technological advantage as well as potentially positive health benefits for consumers (Mehta, Ahlawat, Sharma, & Dabur, 2015), level of inclusion is important to ensure optimal functionality without compromising eating quality. According to the present study, up to 50% inclusion level of PF could have the best potential for consumer acceptability without significant detriment on the overall eating quality. This trend is evident in Table 4 where consumer liking scores for texture and appearance was increasing numerically from 0 to 50% PF inclusion with an observable decline above this level. This is also evident in CATA analysis (Fig. 3) where burgers with PF inclusion > 50% were much closely associated with 100% PF alongside some negative textural attributes.

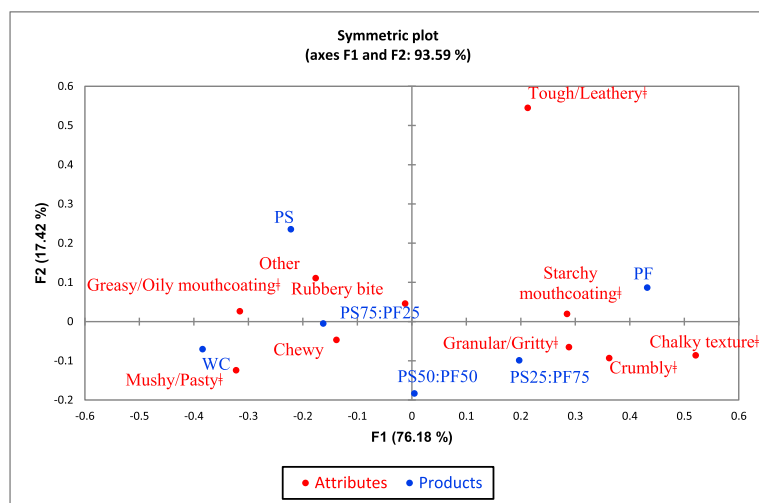


Fig. 3. CATA analysis for beef burger texture attributes as selected by consumers (n = 122). Treatments: WC, wheat crumb, PS, pea starch, PS75:PF25, PS50:PF50, PS25:PF75 pea starch to pea fibre percentage ratio in the binder blend, PF, pea fibre. † Attributes significantly different at $P < .01$, other attributes are not significantly different between treatments.

4. Conclusions

Incorporation of pea fractions into beef burgers had a minimal effect on the colour of fresh burgers and had no influence on the colour stability of raw burgers over 5 days of storage as compared to wheat crumb burgers. All burger treatments containing pea fibre had lower cook loss than those formulated with wheat crumb or pea starch. Wheat crumb burgers were significantly softer, less cohesive and less chewy than treatments incorporated with pea starch and fibre fractions. Firmness of cooked burgers increased with increasing incorporation levels of pea fibre. Consumer acceptability mean scores of all pea starch and pea fibre blends were equivalent to wheat crumb control for all attributes. Consumer acceptability mean scores of all pea starch and pea fibre blends were equivalent to wheat crumb control for all attributes. While not evident in instrumental analysis, panelist feedback suggest that 50:50 blend could present the highest potential for consumer sensory acceptance. The results showed that all combinations of pea starch and fibre can be utilized as gluten free alternatives to wheat crumb for meat binder applications.

Declaration of Competing Interest

None.

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