Physicochemical composition and nutritional properties of foal burgers enhanced with healthy oils emulsion hydrogels

Running title: Foal burgers with healthy emulsion hydrogels

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Summary

This study investigates the effect of animal fat replacement by oil mixture emulsion hydrogels on quality characteristics of foal burgers. Three batches were manufactured: control (CON) - 100% of pork fat; treatment 1 and 2 (T1 and T2) - pork fat was totally replaced using oil mixture emulsions, avocado (T1) or pumpkin seed (T2) mixed with algal oil. These fat replacements were accompanied by a significant decrease in fat content (P<0.001) and colour parameters (P<0.05). Any significant differences in texture were observed in reformulated patties, except for gumminess (P<0.05) and chewiness (P<0.001). Moreover, a healthier fatty acid profile was reached (P<0.001), saturated fat decreased, mono- (T1) and polyunsaturated fatty acids (T2) increased and an improvement of all health indices was observed. However, the sensory acceptability of burgers was unaffected (P>0.05). Thus, these fat reformulations represent a promising strategy to obtain healthier foal burgers with improved nutritional characteristics without affecting sensory properties.

Keywords: foal meat product; healthy burger; animal fat replacers; physicochemical properties; fatty acid profile; sensory acceptance

Introduction

Nowadays, there is a major awareness of the relationship between diet and health. Thus, meat and meat products have gradually acquired a negative connotation, since it is well known that they have a high amount of fat, mainly saturated fatty acids (SFA), cholesterol and other compounds that can damage human health (Barros *et al.*, 2020a). Therefore, in the last decade, both the meat industry and the scientific community have made great efforts to limit the use of animal fat in the production of meat products. There are mainly 3 strategies to replace animal fat with healthier lipids (Domínguez *et al.*, 2021b; Heck *et al.*, 2021; López-Pedrouso *et al.*, 2021). Multiple studies have used microencapsulated oils (Lorenzo *et al.*, 2016; Heck *et al.*, 2018; Vargas-Ramella *et al.*, 2020c), oleogels (Moghtadaei *et al.*, 2018; Martins *et al.*, 2019, 2020) and hydrogels (Heck *et al.*, 2019; Barros *et al.*, 2020b,a; Vargas-Ramella *et al.*, 2020b) with the aim of reformulating meat products. However, recent reviews point out that the use of emulsion hydrogels have several advantages for incorporating oils as substitutes for animal fat in comparison with the use of encapsulation techniques or oleogels (Domínguez *et al.*, 2021a,b). In addition, it is also highlighted that the incorporation of an oil mixture instead of pure oil, allows the optimization of the nutritional value of the final product, limiting its impact on technological or sensory properties (Domínguez *et al.*, 2021a). Consequently, the reformulation of the foal burger is proposed by incorporating an oil mixture immobilized in an emulsion hydrogel. In particular, for this study, algal oil was employed and it was mixed with avocado or pumpkin seed oils to obtain alginate-based emulsion hydrogels.

Algal oil is generally used as good source of long-chain omega-3 fatty acids, like eicosapentaenoic (EPA, C20:5n-3) and docosahexaenoic (DHA, C22:6n-3) acids (Lorenzo *et al.*, 2017). On the other hand, avocado and pumpkin seed oils are untapped sources of health food: avocado oil is a relevant source of monounsaturated fatty acids (MUFA) such as oleic acid (Flores *et al.*, 2019), while in pumpkin seeds oil, polyunsaturated fatty acids (PUFA) (mainly linoleic acid) and MUFA (mostly oleic acid) fractions are the most abundant (Aksoylu Özbek and Günç Ergönül, 2020).

Thus, the objective of this study was to assess the effect of animal fat replacement by healthy oils emulsions hydrogels on proximate composition, physicochemical parameters, fatty acids profile and sensory acceptability of foal burgers.

Materials and Methods

Elaboration of alginate-based emulsion hydrogels

The study was performed in the Centro Tecnolóxico da Carne (CTC) (Ourense, Spain). Algal, avocado and pumpkin seeds oils were employed in the processing of emulsions. Algal oil, containing a high omega-3 concentration (418.3 mg/g docosahexaenoic acid; DHA; C22:6n-3), was kindly provided by Solutex Corporation (Madrid, Spain). Avocado oil (Ethnos, Sevilla, Spain) and pumpkin seed oil (Ecosana, León, Spain) were purchased from a local market. In the present study, two types of alginate-based hydrogels were processed with Prosella powder as gelling agent (Prosella VG NF4, Coli Ingredients, Mittelhausen, France) and elaborated one day before the processing of burgers (de Carvalho *et al.*, 2019; Barros *et al.*, 2020b): Treatment 1 (T1) and Treatment 2 (T2) hydrogels. These emulsions contained algal oil (2.25 g/100 g emulsion) mixed with avocado (T1) or pumpkin seed oil (T2) (35.05 g/100 g emulsion). The fatty acids composition of pork back fat and oils are shown in Table 1.

The Prosella powder can be employ as animal fat replacer and consisted of jellifying agents (calcium sulphate and sodium alginate), wheat glucose syrup (7.4%), a stabilizer (disodium diphosphate, added P_2O_5: 9.58%) and an antioxidant (sodium ascorbate), which retain oils in its structure. Thus, for hydrogel preparations, water (56 g/100g) (pH

7.7 and 10 °f) and algal and avocado or pumpkin seed oils (37.3 g/100 g) were mixed for 1 min in a bowl cutter (Sirman, mod C15VV, Marsango, Italy). Successively, the Prosella powder (6.7 g/100 g) was added and homogenized during 3 min and put in a bowl to rest for 2 h. Once the mix was jellified, it was refrigerated at 4 ºC until the manufacture of the burgers. The final proportion of the emulsions were: water (56 g/100 g), algal and avocado or pumpkin seed oil (37.3 g/100 g) and the prosella powder (6.7 g/100 g).

Burger manufacture

For the present research, three different batches of patties were manufactured in the pilot plant (Figure 1): Control (CON) - containing 100% pork back fat as fat source (10 g/100 g) and other two experimental batches in which animal fat was totally replaced by the alginate-based hydrogels (10 g/100 g) containing algal oil mixed with avocado oil (T1) or pumpkin seed oil (T2), depending on the batch. The other ingredients used in all formulations were lean foal meat (82 g/100 g) (provided by Cárnicas Mutiloa, Rocaforte, Navarre, Spain), salt (1.05 g/100 g) and water (7 g/100 g). In the case of control samples, pork back fat was selected since it is commonly used as fat source in meat products (Vargas-Ramella *et al.*, 2020b). The foal burger processing were carried out according to the procedure reported by Barros *et al.* (2020). It was produced 9 replicates for each formulation and the same elaboration was replicate three times, on different days (9 samples per treatment x 3 experimental treatments x 3 manufacture process runs). After processing, the samples were collected and evaluated for their proximate composition, physicochemical parameters, fatty acids profile and sensory analysis.

Physicochemical, lipid oxidation and composition analysis

The proximate composition, pH, colour, cooking loss and texture profile analysis (TPA) were determined following the procedures described by Vargas-Ramella *et al.* (2020b). The energy content was calculated according to European Commission

Regulation (Regulation (EU) No 1169/2011, 2011). Lipid oxidation was evaluated through thiobarbituric acid reactive substances (TBARS) index using the method described by Vyncke (1975) and values were expressed as mg MDA/kg sample.

Fatty acids analysis

The fatty acids were quantified following the procedure described by Barros *et al.* (2020b). Separation and quantification of the FAMEs was carried out using a gas chromatograph (GC-System 7890B; Agilent Technologies Spain, S.L., Madrid, Spain) with flame ionization detector (FID), following the chromatographic conditions reported by Barros *et al.* (2020b) and data were expressed as g/100 g of fat. The health indices of foal burgers were calculated: n-6/n-3 and PUFA/SFA ratios, atherogenic (AI) [C12:0 + (4*C14:0) + C16:0] / [(ΣMUFA) + (ΣPUFA)] and thrombogenic (TI) [C14:0 + C16:0 + C18:0] / [(0.5*ΣMUFA) + (0.5*n-6) + (3*n-3) + (n-3/n-6)] indices (Ulbricht and Southgate, 1991) and hypocholesterolemic/hypercholesterolemic ratio (h/H) [Σ(C18:1n-9, C18:1n-7, C18:2n-6, C18:3n-3, C20:3n-6, C20:4n-6) / Σ(C14:0 + C16:0)] (Fernández *et al.*, 2007). It is well known that some fatty acids can help to prevent or promote coronary thrombosis and atherosclerosis based on their effect on low-density lipoprotein (LDL) concentration and serum cholesterol. In particular, AI and TI indices reflect the effects of fatty acids on cardiovascular risk, while the h/H ratio indicates the functional effects of fatty acids on cholesterol metabolism (Ulbricht and Southgate, 1991; Fernández *et al.*, 2007).

Consumer evaluation

For sensorial analysis, a total of 39 consumers (with age between 29 and 40 and from both genders) from Ourense (Spain) participated in the test. Restrictions caused by the world state of emergency (September 2020) limited the participation of a major number of tasters, although it was obtained an appropriate number, according to

Mammasse and Schlich (2014). This work consists in a preliminary consumer analysis realized using a home use test (HUT). This methodology was another election caused by the limitations of the pandemic state. The aim of this study was to evaluate consumers' acceptance and preference of the distinct foal burgers elaborated. The treatments were evaluated in raw and cooked samples. Each consumer tasted three samples, one for each formulation, in a single session. Consumers evaluated the foal burgers by the acceptance test using a 7-point hedonic scale, which ranged from "1-disliked much" to "7-liked much", for the following attributes: in raw burgers – visual aspect and odor and in cooked burgers – cooked odor, texture (firmness), juiciness, greasy character, flavor and overall acceptability. In addition, it was asked to order the sample according to their preference (UNE-EN ISO 8589:2010/Amd 1:2017, 2017) using a 3-point scale (1=less favourite ad 3= most favourite). Moreover, specific instructions were provided to consumers. Furthermore, the samples were coded with 3-digit random numbers and it was indicated randomly in which order to taste samples in order to avoid the possible effects of the order of presentation.

Statistical analysis

Statistical analyses were performed using the SPSS statistical software (SPSS 25.0, Chicago, IL, USA). Normal distribution and variance homogeneity were previously tested (Shapiro-Wilk). Data were submitted for analysis of variance (ANOVA), where the parameters were set as dependent variables, treatments (fat source) were considered as fixed effects and replications (the experiment was repeated three times) as a random effect, while for sensory acceptance consumers were additionally included in the model as a random effect (each panellist tasted three samples, one for each treatment, in a single session). The pairwise differences between least-square means were evaluated by Duncan's method. Differences were considered significant if $P<0.05$. The statistical evaluation for the preference test was performed using the Friedman test, with Newell and McFarlene tables (α=0.05). When a significant effect (P<0.05) was found, least significant difference (LSD) test was used as a multiple comparison test.

Results and Discussion

Physicochemical analysis of foal burgers

Proximate composition and physicochemical results of the foal burgers are shown in Table 2. The pork backfat replacement by oil emulsion hydrogels resulted in a significant (P<0.001) increase in moisture and ash values and a decrease in fat and protein contents. A similar trend was reported by previous studies for moisture and ash in beef burgers reformulated with algal oil (Alejandre *et al.*, 2017) and/or wheat germ oil (Barros *et al.*, 2020a), with tiger nut oil (Barros *et al.*, 2020b) and with chia and linseed oil (Heck *et al.*, 2019) compared to conventional formulations (high animal fat percentage). Conversely, Martins *et al.* (2019) found a decrease in moisture and ash in pork patties with partial (75%) animal fat replacement. In the present case, according to recent studies (Barros *et al.*, 2020a,b), the increase in moisture and ash was due to the amount of water (56 g/100 g) and prosella powder (6.7 g/100 g) used to prepare the different emulsions. On the other hand, lipid values significantly decreased (P<0.001) with animal fat replacement (from 9.86 g/100 g in CON to 7.38 g/100 g T1 burgers) and treatments achieved a level of reduction in fat of about 25% (T1) and 23% (T2) compared to control group. These results can be expected considering that pork back fat was substitute for an oil-in-water emulsions which only contained 37.2% of oil. This outcome is in agreement with those previously reported by other authors (Alejandre *et al.*, 2017; Heck *et al.*, 2019; Barros *et al.*, 2020b,a; Vargas-Ramella *et al.*, 2020b), who reformulated burgers with hydrogelled emulsions. Similarly, T1 and T2 burgers reported a significant (P<0.001) reduction in protein content. This result is consistent with data published in literature by other authors, who replaced (partially or totally) pork back fat by emulsion hydrogels in burgers (Heck *et al.*, 2019; Barros *et al.*, 2020b; Vargas-Ramella *et al.*, 2020b), or by fish oil in liver pâté (Domínguez *et al.*, 2017b). Nevertheless, some studies observed an opposite trend (de Oliveira Fagundes *et al.*, 2017; Barros *et al.*, 2020a), reporting a significant increase in protein content of reformulated beef burgers with vegetable oils. In our study, the protein content diminution in T1 and T2 burgers could be related to the fact that animal fat contains about 10% of proteins (Heck *et al.*, 2019), whereas no proteins were added to the emulsion hydrogel (containing only water, oil and gelling agents). All formulations studied (Table 2) can be claimed as "high protein content" according to European Regulation (EC, 2006), since at least 20% of the energy value of the product is provided by protein.

This variation in proximate composition among the three batches was reflected in energy parameters, as could be expected. T1 and T2 samples reported the lowest energy content values compared to CON samples ($P<0.001$), recording a decrease of 14-15%. It is widely known that fat represents the most important component of calorie content. Thus, a diminution in fat content (as occurs in the reformulated burgers) provides a decrease in calorie content. These outcomes agree with data reported by previous researchers (Alejandre *et al.*, 2017; Barros *et al.*, 2020b,a).

Considering lipid oxidation, any significant differences ($P>0.05$) among batches were detected on TBARs values. However, according to previous studies (Alejandre *et al.*, 2017; Barros *et al.*, 2020a,b), the control formulation showed the highest TBARs concentrations (0.30 mg MDA/kg) in comparison to reformulated burgers, T1 (0.25 mg/MDA/kg) and T2 (0.26 mg MDA/kg). Either way, results were all below sensory threshold limits at which consumers perceived rancidity (de Carvalho *et al.*, 2019). It is well known that highly unsaturated fatty acids (UFA) are more susceptible to the oxidative degradation than SFA (Domínguez *et al.*, 2019). However, despite the high concentration of UFA in avocado, pumpkin seed and algal oils (Table 1), T1 and T2 burgers were not affected by oxidation. Barros *et al.* (2020) confirmed that oleic acid (the major fatty acid in avocado oil) is less sensitive to oxidative processes than PUFAs, which could explain our results. Moreover, according to recent studies (Alejandre *et al.*, 2017; Serdaroğlu *et al.*, 2017; Barros *et al.*, 2020a,b), the presence of natural antioxidants in the oils and the protective action of the emulsion hydrogel (immobilized oil) against oxidizing agents could justify our outcomes.

Instrumental colour (L*, a* and b*) of foal burgers was affected by the incorporation of oil emulsion hydrogels ($P<0.05$). This trend is consistent with data reported by other authors (de Souza Paglarini *et al.*, 2019; de Carvalho *et al.*, 2020; Vargas-Ramella *et al.*, 2020c), who observed significant differences on colour values in meat products reformulated with different vegetables oils as animal fat replacers. On the contrary, analogous studies (Pires *et al.*, 2019; Barros *et al.*, 2020a) did not detect significant difference on colour parameters among the different treatments. However, our results and the presence of distinct outcomes in literature could be related to the different oil characteristics and composition, the emulsion properties and the other ingredients used in the meat product formulation (Barros *et al.*, 2020a). In particular, Table 2 showed that pork fat replacement decreased significantly L* and a* values, while T1 burgers reported the highest b* values. In all cases, the lowest values were detected in T2 burgers, whose values are in line with the characteristic greenish colour of pumpkin seed oil (visual assessment) (Figure 1).

As regards pH, values were not affected by the animal fat replacement for oils emulsion hydrogels ($P>0.05$). These results are in accordance with previous authors (Martins *et al.*, 2019; Pires *et al.*, 2019; Barros *et al.*, 2020a), who observed that fat source did not significantly affect the meat products reformulated with vegetable oil emulsions. Moreover, reformulated burgers reported significantly (*P*<0.01) lower cooking loss values compared to CON treatment (25.01% in T1 and 22.85% in T2 *vs.* 27.14% in CON treatments). Similarly, recent findings observed that cooking loss decreased in beef burgers elaborated with vegetable oils as back fat replacers (Gómez *et al.*, 2018; Moghtadaei *et al.*, 2018; Barros *et al.*, 2020b). In our case, this diminution could be justified by the use of alginate in the emulsion hydrogel, which acted as barrier against liquid loss during cooking in (Moghtadaei *et al.*, 2018).

Considering texture parameters, only gumminess and chewiness were affected (*P*<0.05) by healthier fat reformulation. Hardness, springiness and cohesiveness were similar in all treatments (*P*>0.05). In particular, T2 burgers reported the lowest values in gumminess (*P*<0.05) and chewiness (*P*<0.001) compared to the other two formulations. Whereas, T1 burgers presented an opposite behaviour, showing a firmer texture and the highest values, especially in gumminess and chewiness. This trend is according to the results of other authors, who reported an increment in chewiness (de Oliveira Fagundes *et al.*, 2017; Heck *et al.*, 2019) and in gumminess (de Oliveira Fagundes *et al.*, 2017) in reformulated batches. On the other hand, our results disagree with data reported by recent studies (Alejandre *et al.*, 2019; Paglarini *et al.*, 2019; Barros *et al.*, 2020b; dos Santos *et al.*, 2020; Vargas-Ramella *et al.*, 2020b), where any significant differences were observed in reformulated meat products containing oil emulsions as animal fat replacers. On the whole, in our study, it is complicated to relate the different behaviour of batches to a single factor, since relevant differences in proximate composition were detected (protein, lipid, and ash content) (Barros *et al.*, 2020a). Moreover, the distinct features of selected oils, the different physicochemical characteristics between animal fat and oil-in-water emulsions employed and their interaction with meat could explain part of the textural differences among batches.

Fatty acids and health indices of foal burgers

The fatty acids contents (g/100 g fat) and health indices of the different foal burgers are shown in Table 3 (only those represented >0.1%). Unsurprisingly, the replacement of pork back fat by T1 and T2 alginate-based emulsion hydrogels affected the lipid profile of burgers. As regards SFA, palmitic (C16:0) and stearic (C18:0) acids were the most abundant, especially in CON batches. However, coinciding with the literature (Heck *et al.*, 2019; Barros *et al.*, 2020a,b; Vargas-Ramella *et al.*, 2020a,b), the substitution of animal fat by healthy oil formulations produced a statistically significant reduction of SFA fraction ($P<0.001$) compared to the conventional meat products. These outcomes are related with the significant lower values of C16:0 and C18:0 obtained in the reformulated samples. In this manner, it is obtained an important reduction of SFA with atherogenic, hypercholesterolemic (C16:0) and thrombogenic (C16:0 and C18:0) effects (Fernández *et al.*, 2007; Montesano *et al.*, 2018).

MUFA content also resulted be affected by the type of fat source employed ($P<0.001$). Among them, oleic acid (C18:1n-9) represented the prevalent fatty acids in all of the cases, with concentrations ranging from 29.29 to 35.69 g/100g of fat, where the highest values belonging to T1 batch. Similarly, other individual MUFA such as palmitoleic (C16:1n-7) and cis-vaccenic acids (C18:1n-7) showed the highest values in T1 burgers. These outcomes agree with what previously reported by Rodríguez-Carpena *et al.* (2012), studying the partial substitution (50%) of animal fat by avocado oil in burger patties. Additionally, significant MUFA increment was observed in other studies, where tiger nut (Barros *et al.*, 2020b; Vargas-Ramella *et al.*, 2020b), canola (Alejandre *et al.*, 2019; Vargas-Ramella *et al.*, 2020a), olive and soybean oils (Vargas-Ramella *et al.*, 2020a) emulsion hydrogels were investigated as animal fat replacers.

Moreover, data showed statistically significant differences (P<0.001) in PUFA concentrations among treatments and T2 burgers reported the highest values compared to CON and T1 samples. Linoleic acid (C18:2n-6) was the most abundant in the three formulations (P<0.001), although it was predominant in T2 batch. This outcome could be expected since pumpkin seed oil has a high linoleic content as showed in Table 1 (39.60 g/100g of oil), which explained also the highest omega-6 (n-6) concentration in T2 samples. Whereas, among omega-3 fatty acids (n-3), α-linolenic acid (C18:3n-3) was the most abundant in T1 samples (P<0.001). In addition, the presence of algal oil in the emulsion hydrogels increased omega-3 fatty acids (n-3) of reformulated burgers (P<0.001). In fact, as previously mentioned, it is recognized that marine oils contains high amounts of long-chain n-3 (LC n-3), as eicosapentaenoic (EPA, C20:5n-3) and docosahexaenoic (DHA, C22:6n-3) acids (Munekata *et al.*, 2020). This is confirmed and reflected in our data, where reformulated burgers contained 94.80 mg EPA+DHA/100 g of burger (T1 samples) and 98.73 mg EPA+DHA/100 g of burger (T2 samples) (data not shown). Thus, they could be claimed as "source of omega-3 fatty acids" and "high omega-3 content", according to the European Parliament (Regulation (EU) No 116/2010, 2010), which establishes a minimum of 40 mg and of 80 mg of the sum of EPA and DHA per 100 g of product, respectively. Our results are consistent with those obtained by other authors (Alejandre *et al.*, 2019; de Souza Paglarini *et al.*, 2019; Heck *et al.*, 2019; Barros *et al.*, 2020a,b; Vargas-Ramella *et al.*, 2020b), who observed a relevant increase of PUFA proportions in meat products reformulated with vegetable and/or marine oils as pork back fat substitutes. In particular, in line with the oils employed, the authors observed an increase of omega-6 and/or omega-3 fractions, similar to ours.

Therefore, as general conclusion, it seems that the lipid profile of the burgers reflects the fatty acid composition of the fat source employed in their formulation. As well as, several studies about reformulated burgers (de Oliveira Fagundes *et al.*, 2017; Heck *et al.*, 2017, 2019; de Carvalho *et al.*, 2019; Barros *et al.*, 2020b,a; Vargas-Ramella *et al.*, 2020b) reported the same conclusions.

Regarding the nutritional values of foal burgers (Table 3), T1 burgers recorded the lowest n-6/n-3 ratio (3.01) among all formulations (P<0.001). As described above, T1 emulsion hydrogel modified both n-6 and n-3 contents in foal burgers, reducing the n-6/n-3 ratio and obtaining a value minor than 4, according to the recommendation of the n-6/n-3 ratio (Simopoulos, 2004). Whereas, T2 and CON samples exceeded the recommended ratio by 2.91 and 2.64, respectively. However, it is worth mentioning that results derived by n-6/n-3 ratio should not to be considered alone. Moreover, it is relevant to observe that pork back fat replacement by T1 and T2 emulsion hydrogels increased the PUFA/SFA ratio (P<0.001), recording values above 0.4 (0.46 in T1 and 0.85 in T2), as recommended (Wood *et al.*, 2008). These outcomes represented an important improvement in the nutritional characteristics of the fatty acids composition of foal burgers. Similar results were obtained by other authors, replacing animal fat with vegetable fat sources in meat products (Heck *et al.*, 2019; Pires *et al.*, 2019).

In addition, following the recommendations, healthy products should have AI and TI as low as possible (Ulbricht and Southgate, 1991), while h/H should be high. In our study, in both reformulated burgers were observed a decrease of TI and AI indices and an increase of h/H index compared to CON treatment (P<0.001), evidencing the improvement of the lipid profile obtained with the substitution of animal fat by healthy vegetable oil emulsion hydrogels. Similar to the present study, other authors found a reduction in TI and AI and an increment of h/H index in meat products applying vegetable oil emulsions as fat replacers (Domínguez *et al.*, 2016, 2017a,b; Heck *et al.*, 2019; Barros *et al.*, 2020b). Thus, the reformulations employed confers healthier characteristics to the final products. As regards algal oil, although it presents high SFA and low MUFA contents, it has an elevated PUFA content, being a precious source of omega-3 fatty acids as commented above (Table 1). Thus, the presence of algal oil in the emulsion hydrogels surely favored and took part to the improvement of the lipid profile of our reformulated burgers, also by a nutritional standpoint.

Consumer evaluation of foal burgers

Table 4 presents the acceptance test results for the different burger treatments. Any significant differences (P>0.05) among formulations were detected by consumers in the acceptance test, reporting similar values for all sensory parameters. Data showed a tendency among batches only for flavour attribute (P<0.1), where T1 samples recorded the lowest values compared with the other two batches (3.7 for T1 *vs.* 4.6 for CON and T2 samples). The low acceptability of T1 samples could be justified by its characteristic flavour, which is not described as a typical burger flavor. However, when overall acceptance was studied, although T2 and CON obtained the same scores (4.6) and higher than T1 burgers (3.8), no differences were detected among the three formulations (P>0.05). It is possible to affirm that all formulations were considered "accepted", recording values higher than 3.5 (acceptability limit). Thus, these outcomes indicated that the use of T1 and T2 emulsion hydrogels as animal fat replacers did not alter the sensory acceptability of foal burgers. Our results are consistent with previous studies realized by other researchers, who reported that 100% animal fat substitution by algae oil (Alejandre *et al.*, 2017), tiger nut oil (Barros *et al.*, 2020b; Vargas-Ramella *et al.*, 2020b), chia or linseed oils (Vargas-Ramella *et al.*, 2020b) emulsion hydrogels in burgers did not affect the consumer acceptability.

As regard preference test, it allows to understand how differently the consumer's perception of the three burger formulations was. Total scores of preferences (number in brackets in Table 5) showed that CON and T2 samples were the most chosen (most favourite) by the consumers, while the T1 burgers were the least favourite. However, Friedman's test indicated that total preference was unaffected (P>0.05) by the type of fat source included in the formulations (F_{test}<F=0.05). Thus, taking into account the results obtained from the sensorial analysis, T1 and T2 emulsions could represent successful pork back fat replacers since their incorporations did not modify the global acceptance of the final products.

Conclusions

The use of T1 and T2 emulsions as pork back fat substitutes was able to reduce the fat amount, increase the product yield and elaborate healthier burgers, according to their characteristics. Reformulated burgers showed a significant reduction of the energy content according to the proximate composition changes. Both alginate-based hydrogel emulsions reduced SFA content, T1 formulation increased MUFA content (especially oleic acid), while T2 raised PUFA fraction (particularly linolenic acid) in foal burgers. The presence of algal oil in both emulsions provided an added value to the products, since increased the omega-3 content (in particular DHA), allowing to claim the reformulated burgers as "high omega-3 content" and "source of omega-3". Furthermore, both formulations improved health indices, obtaining PUFA/SFA, TI, AI and h/H values in line with the health recommendations. In addition, T1 burgers reduced n-6/n-3 ratio, obtaining a value <4, as recommended. Moreover, the inclusion of these hydrogels showed to not affect sensory acceptability. Further studies are necessary to improve technological features of the reformulated burgers (as colour and texture). Thus, as a general conclusion, the use of emulsion hydrogels is a promising strategy to develop healthy burger without affecting sensory properties.

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Ethical Guidelines

Ethics approval was not required for this research.

Conflict of interest

The authors declare that there are no conflicts of interest.

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This study aimed to reformulate beef burgers to make them healthier through total replacement of pork backfat by algal and/or wheat germ oils emulsions. The use of algal and/or wheat germ oils emulsions increase PUFA concentration. Beef burgers containing algal oil can be claimed as "high omega-3 content". Both oils improved the n-6/n-3 and PUFA/SFA nutritional ratios.

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