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REVIEW ARTICLE

Strategies for producing healthier chicken nuggets – a review

Estratégias para produção de nuggets de frango mais saudáveis – uma revisão

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Abstract

The aim of this review was to address some alternatives that can be applied to turn chicken nuggets into healthier products. One of the alternatives is to reduce the sodium content in nuggets by replacing sodium chloride with other salts, without affecting their sensory and technological properties, and to balance the consumption of mineral salts in the body. The addition of fibres can improve nutritional and functional properties when incorporated into meat products because they increase water and oil retention capacities. Reformulation of meat products by adding vegetable oils with low saturated and high unsaturated fatty acids contents makes breaded meat products healthier. The oil absorption by foods during frying can be reduced by the use of coating systems that serve as a barrier to protect the product. Therefore, different strategies have been used with the aim of making chicken nuggets healthier, due to the addition of functional compounds, the reduction in the fat content, the improviment in the lipid profile, the reduction of the sodium content in the nuggets and the increasing in the consumption of minerals. It is expected that new studies can be evaluated and applied within the industrial scale that can serve the entire population, even though it is a fried meat product, but that has a reduced sodium content and high functional compounds.

Keywords: Breaded meat product; Fatty acid; Fibres content; Oil absorption; Sodium reduction.

Resumo

O objetivo desta revisão foi abordar as alternativas que podem ser aplicadas para tornar os nuggets de frango um produto mais saudável. Uma das alternativas para reduzir o teor de sódio nos nuggets é a substituição do cloreto de sódio por outros sais, para, sem afetar suas propriedades sensoriais e tecnológicas, equilibrar o consumo de sais minerais no organismo. A adição de fibras pode melhorar as propriedades nutricionais e funcionais quando incorporadas aos produtos cárneos, pois aumentam a capacidade de retenção de água e óleo. A reformulação de produtos cárneo com melhor perfil lipídico, com baixo teor de ácidos graxos saturados e alto teor de ácidos graxos insaturados, torna o produto cárneo empanado mais saudável. A absorção de óleo durante a fritura pode ser reduzida com o uso de sistemas de revestimento que sirvam de barreira para proteger o produto. Portanto, diferentes estratégias têm sido utilizadas com o objetivo de tornar os nuggets de frango mais saudáveis, devido a adição de compostos funcionais, redução do teor de gordura e melhora do perfil lipídico, redução do teor de sódio e aumento do teor de minerais. Desta forma, espera-se que novos estudos possam ser avaliados e aplicados dentro da escala industrial e que possam atender toda a população. Assim, embora seja um produto cárneo frito, possa apresentar um teor de sódio reduzido e com alto teor de compostos funcionais.

Palavras-chave: Produto cárneo empanado; Ácidos graxos; Teor de fibras; Absorção de óleo; Redução de sódio.

Highlights

- Addition of fibres in chicken nuggets can improve functional and nutritional properties
- Different coating systems can decrease oil absorption by nuggets during frying
- Use of emulsion gel can be used as a strategy to improve the lipid profile in meat product

1 Introduction

Chicken nugget was developed by Robert C. Baker in 1950, professor of food science and poultry science at Cornell University in the United States of America (USA). Baker also found a way to keep breading linked to nuggets during the frying stage (Cornell University, 2006). However, the study was not patented and in 1979 the McDonald's corporation patented its formulation of Chicken McNuggets, beginning to be marketed in 1980. Currently, breaded meat products have more space in the convenience food market due to their convenience, that is, for being a processed product, ready to fry and serve and to be consumed by all age groups and income (Barbut, 2012).

However, these products have been the target of negative perceptions by consumers deserving special attention in terms of reformulation, since they are high in fat and sodium. A major concern regarding the consumption of breaded products, mainly chicken nuggets, is because they are fried products. About 10% of the oil will be absorbed by the coating system of the nuggets during frying (Barbut, 2015). Alternatives that reduce fat content and improve the lipid profile of chicken nuggets can be by replacing the usual fat source, i.e., the chicken skin with functional compounds, as chia flour or vegetable oils and the modification of the coating system, through the addition of hydrocolloids, starches and gums (Barros et al., 2019b; Kurek et al., 2017; Verma et al., 2015; Oztop et al., 2014).

Another strategy to make healthier chicken nuggets is the incorporation of functional ingredients. Several studies have been developed aiming at improving the nutritional quality of chicken nuggets by adding fibers or improving the lipid profile, by increasing omega-3 fatty acids (Verma et al., 2012; Yogesh et al., 2013; Pérez-Palacios et al., 2018). These reformulation strategies may provide several health benefits to the consumer, such as the reduction of the risk of cancer, diabetes, and neurological diseases, among others (Shahidi & Ambigaipalan, 2018).

In addition, the reduction of sodium content in breaded meat products is capable of reducing the risk of cardiovascular diseases (Rosamond, 2002), since 1.5 g/100 g to 2.5 g/100 g of sodium chloride (NaCl) is added in traditional formulations of chicken nuggets (Yogesh et al., 2013; Barros et al., 2019a). Several salts can be used as substitutes for sodium chloride in meat products, such as calcium chloride, potassium chloride, and magnesium chloride. In the study carried out by Barros et al. (2019b), the substitution of 75% of the added NaCl with $CaCl_2$, with the same ionic strength and equivalent to 1.5% NaCl in chicken nuggets, caused a reduction of up to 43% sodium.

Therefore, this review aimed to address alternatives that can turn nuggets into healthier products, by adding of dietary fibres, improving the lipid profile and low-fat content, reducing the sodium content and changing the coating system.

2 Strategies to make healthier nuggets

2.1 Reduction of sodium content

In recent years there has been a concern about the excess sodium present in processed foods. According to the Food Standards Agency (2016), about 75% of the sodium chloride intake is present in processed foods. Due to the high sodium content in meat products, the meat industry and consumers became more aware of sodium intake and arterial hypertension, resulting in increased demand for meat products with low sodium content (Ruusunen & Puolanne, 2005). In order to prevent problems caused by excess sodium in foods, the World Health Organization (WHO) (World Health Organization, 2013) recommends that sodium chloride intake be a maximum 5 g/day. Therefore, several studies have been carried out to replace sodium chloride with different salts in meat products, such as calcium chloride, magnesium chloride, and potassium chloride, among others (Almeida et al., 2016; Santos et al., 2017). However, it should be noted that the presence of divalent cation ions may contribute for the reduction of myofibrillar protein extraction and affect the technological properties of meat products (Horita et al., 2011).

Verma et al. (2015) evaluated the quality of low-fat chicken nuggets added with a salt substitute blend (0.2% of potassium chloride, 1% of sucrose, 0.03% of acid citric and 0.03% of acid tartaric) and pea hull flour, and verified that due to the salt replacement, decreased the product yield and emulsion stability in low fat chicken nuggets. Chicken nuggets with a low amount of sodium chloride may result in a decrease in the concentration of extracted protein, involved in the formation of the gel/emulsion matrix. Since NaCl plays a significant role in extracting proteins from meat, so it binds water and fat, stabilizing meat mass (Verma et al., 2012).

Regarding sensory evaluation, Yogesh et al. (2013) studying different concentrations of NaCl (2.5%, 2%, 1.5% and 0%) and fat (5% and 0%) in chicken nuggets, found that the nuggets containing the highest amount of fat and salt had the best sensory acceptance. Salinity decreased with the reduction of NaCl, negatively affecting the palatability of meat products.

One of the alternatives to reduce the sodium content in chicken nuggets by replacing NaCl with other salts, without affecting their sensory and technological properties, would be to maintain the same ionic strength. According to Barros et al. (2019a) replacing up to 75% of sodium chloride with calcium chloride with ionic strength equivalent to 1.5% NaCl (IS = 0.256) in chicken nuggets did not affect their physicochemical characteristics. Furthermore, these same authors observed that, although calcium chloride is a divalent salt and may negatively affects the acceptability of meat products when maintaining the same ionic strength, a smaller amount of $CaCl_2$ was needed in the nuggets formulation, resulting in nuggets with good sensory acceptance. Armenteros et al. (2012) verified that the presence of calcium and magnesium salts affected the acceptability of the meat product. The divalent cations, such as those of calcium and magnesium, presented bitter taste and metallic or astringent sensations (Yang & Lawless, 2005).

Despite few studies involving the reduction of sodium content in breaded meat products are available, it is relevant to reduce the sodium content in this type of meat product, mainly with the addition of other salts that can balance the consumption of mineral salts in the body. According to Horita et al. (2014), the use of chloride salt mixtures ($CaCl_2$, KCl and NaCl) as partial substitutes for NaCl may favor the balanced ingestion of minerals in the meat product. They also verified that the use of 25 or 50% $CaCl_2$ to substitute NaCl revealed a sensorial solution to reduce Na in the low-cost frankfurter sausage since such formulations were not different from the control in flavour. The replacement of NaCl with $CaCl_2$ in chicken nuggets is an alternative to increase calcium intake (Barros et al., 2019a). Barros et al. (2019a) observed that the consumption of one portion (130 g) (Brasil, 2003) of chicken nuggets with the replacement of 75% NaCl by $CaCl_2$ (with ionic strength equivalent to 1.5% NaCl) could provide 16.9% of the recommended daily intake for adults in Brazil (Brasil, 2005), once the presence of calcium chloride did not affect nuggets sensory acceptance.

Other alternatives have been studied as a substitute for NaCl, without affecting the perception of saltiness in meat products, application of new technologies such as ultrasound or high pressure processing to neutralize defects in meat products with low salt content, and reducing the size of the salt particles and altering salt morphology to increase saltiness perception (Rodrigues et al., 2021; Inguglia et al., 2017).

Inguglia et al. (2017) verified that Yeast extract, a natural ingredient, also has potential as a flavor enhancer in sodium-reduced meat products. Rangel-Vargas et al. (2021) studied the use of common edible mushrooms as an ingredient and additive substitute, using them in fresh, dried or even extract form, as salt substitutes. Akesowan & Jariyawaranugoon (2021) verified that the inclusion of 20% of fresh *Agaricus Bisporus* as meat extender combined with eggplant powder, to replace up to 40% of salt in chicken nuggets, was only suitable for salt reductions of 13%. Therefore, future studies on the application of these strategies in chicken nuggets are needed.

2.2 Addition of dietary fibres

Dietary fibres are divided into two groups: soluble fibres (e.g., pectins, gums, oat bran, and barley meal), whose function is to lower blood cholesterol; and insoluble fibres (e.g., wheat bran), which have less effect on the viscosity of the intestinal contents, increasing the stool size (Slavin, 2008; Verma & Banerjee, 2010). It is recommended a minimum fibres consumption of 25 g/day on a 2000 kcal diet (Brasil, 2003), since fibres consumption may reduce obesity, constipation, glucose levels, blood pressure, and cardiovascular disease (Bernaud & Rodrigues, 2013).

Therefore, the addition of fibres in food products is becoming important for the food industry, as refined flours bakery, beverages, dairy and meat products, because it improves the nutritional value of products and contributes to competitiveness (Verdú et al., 2017). In addition, fibres have functional properties when incorporated into foods because they increase water and oil retention capacities, prevent syneresis, form emulsions and/or gels, modify texture, stabilize fat-rich foods and emulsions, and improve the shelf life of the products (Elleuch et al., 2011).

Choe et al. (2013) studied the effect of a mixture of pork skin and wheat fibres (40 g/100 g pork skin, 20 g/100 g wheat fibres and 40 g/100 g water) as a substitute for fat in frankfurter-type sausages, and found that the addition of up to 15 g/100 g of this blend was able to reduce the cooking loss and increase the emulsion stability and viscosity due to the excellent ability of the fibre to retain water and fat. Verma et al. (2015), when evaluating low-fat chicken nuggets enriched with 8, 10, and 12 g/100 g pea hull flour, found that the nuggets added with fibres presented reduced total cholesterol and glycolipid levels of 8% and 12%, respectively, in function of the addition of the fibres in the formulation.

Verma et al. (2012) studied low-fat nuggets made with sodium chloride replacement (with potassium chloride, citric acid, tartaric acid, and sucrose) and with addition of different proportions (5, 7.5 and 10 g/100 g) of chickpea hull flour, observed that the presence of chickpea hull flour increased fibres content and reduced cholesterol levels, however, the incorporation of fibres above 5 g/100 g caused low sensory acceptance. Santhi & Kalaikannan (2014), studying the incorporation of 10 g/100 g and 20 g/100 g of oat flour into low fat chicken nuggets, found an increase in fibres content in the formulations containing oat flour and that the addition of up to 10 g/100 g was considered acceptable by the consumers.

Barros et al. (2018) reformulated a fiber-enriched chicken nugget with the addition of chia flour as a substitute for chicken skin (5%, 10%, 15% and 20%). These authors observed that the formulation containing more than 15% of substitution provided a product that could be labeled as “high fiber content” (Brasil, 2012). They estimated that the consumption of a portion (130 g) of chicken nuggets containing 10% of chia flour

(2.66 g dietary fibre/100 g or 3.46 g/130 g), could provide 14% of the recommended daily fibre intake according to Brazilian legislation (Brasil, 2003).

The used ingredients as animal fat substitutes are fibers and vegetable oils. The technical regulations of identity and quality of meat products do not mention the use of fibres in meat products (Rios-Mera et al., 2021). However, in chicken nuggets, breading agents such as wheat flour can certainly be added, a promising alternative adding fiber with the breading function may be a viable strategy for incorporating fiber into nuggets.

2.3 Improvement of the lipid profile

Reducing saturated fat intake is a recommended strategy to help reduce the risk of certain cardiovascular diseases. The WHO recommends that fat consumption be between 15% and 30% of the total daily energy intake, with 10% of this total comprised by saturated fat, while the rest should be from mono and polyunsaturated fats (World Health Organization, 2013).

The reformulation of meat products with better lipid profiles is one of the strategies that has been studied for the development of functional foods and is generally based on replacing the animal fat normally present in the meat product, with another fat or oil presenting a lower amount of saturated fatty acids (SFAs) and a higher amount of unsaturated fatty acids [monounsaturated (MUFAs) or polyunsaturated (PUFAs)]. There are several plant and marine lipid sources that can help provide these nutritional and functional benefits to varying degrees (Jiménez-Colmenero, 2007). Some categories are more critical when the objective is reformulation with a focus on healthier restructured products, such as the chicken nuggets, that undergo frying processes, increasing the lipid content, in addition to the normally present in formulations.

The α-linolenic acid (belongs to omega-3 family – n3) is a polyunsaturated fatty acid (C18:3) essential in the diet, mainly because it is not synthesized by humans. The adequate consumption of α-linolenic acid in the diet for men and women over 19 years old is 1.6 g/day and 1.1 g/day, respectively (Trumbo et al., 2002). The consumption of omega-3 fatty acids is of extreme importance because it can promote several benefits, such as, reducing the incidence of cardiovascular diseases, atherosclerosis, hypertension, obesity, and inflammatory diseases, among others (Yashodhara et al., 2009). The α-linolenic acid is found in chloroplasts of green leafy vegetables and in flax, chia, rape, walnuts, and perilla seeds (Simopoulos, 2016).

In meat and meat products the presence of omega-3 fatty acids is relatively low; therefore, their increase in these products is particularly important (Bernardi et al., 2016). In the work carried out by Barros et al. (2018), it was verified that the addition of 10% chia flour replacing chicken skin in chicken nuggets was able to make the meat product healthier, by improving the lipid profile (increasing omega-3 content; α-linolenic acid) and decreased in the omega-6/omega-3 ratio.

Barros et al. (2019b) studying the substitution of 10% chicken skin by chia flour in chicken nuggets, with and without sodium reduction, observed that due to the high content of α-linolenic fatty acid in chia flour (68.52 g/100 g), there was an increase in the content of polyunsaturated fatty acids (PUFAs) in chicken nuggets containing 10% of chia flour (Segura-Campos et al., 2014). These same authors also found that chicken nuggets containing 10% of chia flour can be labeled as “high omega-3 content” (Brasil, 2012; European Union, 2010).

Despite few studies involving the improvement of the lipid profile in nuggets, more studies are relevant to replace animal fat with sources rich in omega-3 fatty acid, thus increasing the intake of daily consumption of omega-3 (α-linolenic acid) and decreasing the omega-6/omega-3 ratio.

The trend today is no longer to directly incorporate healthy oils but to incorporate them along with oleogels, hydrogels, bigels, among other technologies (Barros et al., 2021; Lorenzo et al., 2016), which may be promising alternatives in the reformulation of chicken nuggets as a substitute for animal fat. Barros et al. (2020) using tiger nut (*Cyperus esculentus* L.) oil emulsion as a substitute for animal fat (50% and 100%) in beef burgers, found that it was possible to reduce 32% of the fat.

Evaluating the properties of low-fat and gluten-free chicken nuggets by Carvalho et al. (2018) found that the formulations without the addition of soybean oil had a low-fat content, a reduction of 73%. However, these authors were also able to verify that in the formulation containing soybean oil, the lipid content is about 30% to 41% lower than the content of commercial chicken nuggets. Alrawashdeh & Abu-Alruz (2022) verified the produce low-fat and high-fibre chicken nuggets by adding dietary fibres and, at the same time, reducing chicken skin in varying proportions (30 – 0%), observed that the complete replacement of chicken skin with 15% of fibres, reduced the fat content in 31.24%.

2.4 Coating system: oil absorption

The deep fat frying process results in foods with a high amount of lipids/oil. Consumption of high-fat fried foods has the potential to cause health problems such as obesity, hypertension, cardiovascular disease and high cholesterol levels (Dourado et al., 2019).

The use of deep fat frying is a technique widely used in many industries, businesses, and homes, as it provides flavor, appearance, aroma and texture (crispness) to foods. The main limitation of deep fat frying is the fact that the water present in the food, at high temperatures, is progressively evaporated during frying and partially replaced by oil, constituting up to 50% of the fat of the total weight of some products (Kurek et al., 2017).

The frying process involves heat and mass transfer, in which the high temperature of the oil (about 160 to 180 °C) allows for rapid heat transfer and a short cooking time. Surfactant formation provides only a partial explanation for increased oil absorption during prolonged frying. When moisture is lost through evaporation, large pores are formed on the surface of the meat product, thus facilitating the entry of oil. When the food is removed from the fryer, the effect of the cooling phase explains the significant amount of oil absorbed and the characteristics of the food and oil viscosity are the main ones in the oil absorption. Finally, during the frying process, chemical reactions such as polymerization, hydrolysis, and oxidation occur due to the formation of volatile and non-volatile compounds that can result in surface tension resulting in greater oil absorption capacity (Dana & Saguy, 2006; Ananey-Obiri et al., 2018; Liberty et al., 2019).

Therefore, the oil absorption by foods during frying can be reduced by the use of coating systems that serve as a barrier to protect the product. The coating system is determined by its barrier and mechanical properties, and its effectiveness depends on its composition and microstructure and on the characteristics of the substrate (Ananey-Obiri et al., 2018). Therefore, research in search of the incorporation of components capable of altering the reactions that result in lower oil absorption has been investigated.

The use of hydrocolloids in the coating system can reduce oil absorption due to their gelling properties by forming a very thin film around the product and at the same time provide an improvement in adhesion, viscosity, and pick-up of the batter and not negatively influence the sensory attributes of fried foods (Varela & Fiszman, 2011). Sahin et al. (2005) observing the effects of various gum types (hydroxypropyl methylcellulose (HPMC), guar gum, xanthan gum, and arabic gum) on the quality of deep-fat fried chicken nuggets, found a significant reduction in oil absorption (< 2.5%) in nuggets containing HPMC and xanthan gums compared with other gums and the control. Also, the arabic gum when added to the batter formulation could be noted a product with the highest oil content and porosity was obtained.

Chayawat & Rumpagaporn (2020), studying the effects of four defatted rice bran substitution levels (0, 10, 15 and 20% of mixed flour in batter and pre-dust) on a fried chicken nugget, verified an increase in the batter viscosity and pickup with increased defatted rice bran substitution levels, thus resulting in thicker nugget crusts and decreasing oil content while the fiber content increased. Therefore, 15% or less defatted rice bran as a substitute in batter reduces fried chicken nuggets' oil content while maintaining meat product quality and making it healthier. A reduction in the absorbed oil content was also observed by Kumcuoglu & Cagdas (2015), when they studied the effect of batter containing seed grape powder on the quality of chicken nuggets. In addition, these authors verified that the seed grape powder increased the pick-up of the restructured meat product.

Martelli et al. (2008) studied the effect of the edible coating containing methylcellulose (1 g/100 g of solution) and cassava starch (4 g/100 g of solution) with 25 and 55 g de glycerol/100 g of biopolymer, applied before the breading system, on oil absorption during chicken nuggets frying. They verified a reduction in the oil absorption and improvement in the water retention of the nuggets during the deep fat frying process in relation to the control formulation.

3 Conclusion

Different strategies have been studied with the aim of making chicken nuggets healthier, due to reducing the total or saturated fats and sodium contents, besides the addition of functional compounds like fibres. Different evaluated strategies were able to improve the lipid profile, through the replacement of animal fat with vegetable oil or using improved coating systems. The addition of different fibres sources, besides their healthy properties, also increased water and oil retention capacities when incorporated into chicken nuggets. In relation to sodium reduction, the replacement of sodium chloride with other salts proved efficient in reducing the sodium content and increasing the consumption of desired minerals, such as calcium.

In this way, it is expected that new studies can be evaluated and applied within the industrial scale and that it can serve the entire population, even though it is a fried meat product, that has a reduced sodium content and high functional compounds.

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References

Akesowan, A., & Jariyawaranugoon, U. (2021). Optimization of salt reduction and eggplant powder for chicken nugget formulation with white button mushroom as a meat extender. *Food Research*, *5*(1), 277-284. http://dx.doi.org/10.26656/fr.2017.5(1).380

Almeida, M. A., Villanueva, N. D. M., Pinto, J. S. S., Saldaña, E., & Contreras-Castillo, C. J. (2016). Sensory and physicochemical characteristics of low sodium salami. *Scientia Agrícola*, *73*(4), 347-355. http://dx.doi.org/10.1590/0103-9016-2015-0096

Alrawashdeh, H., & Abu-Alruz, K. (2022). Development of high-fiber, low fat chicken nuggets. *International Journal of Food Studies*, *11*(2), 354-373. http://dx.doi.org/10.7455/ijfs/11.2.2022.a8

Ananey-Obiri, D., Matthews, L., Azahrani, M. H., Ibrahim, S. A., Galanakis, C. M., & Tahergorabi, R. (2018). Application of protein-based edible coatings for fat uptake reduction in deep-fat fried foods with an emphasis on muscle food proteins. *Trends in Food Science & Technology*, *80*, 167-174. http://dx.doi.org/10.1016/j.tifs.2018.08.012

Armenteros, M., Aristoy, M. C., Barat, J. M., & Toldrá, F. (2012). Biochemical and sensory changes in dry-cured ham salted with partial replacements of NaCl by other chloride salts. *Meat Science*, *90*(2), 361-367. PMid:21871742. http://dx.doi.org/10.1016/j.meatsci.2011.07.023

Barbut, S. (2012). Convenience breaded poultry meat products – new developments. *Trends in Food Science & Technology*, *26*(1), 14-20. http://dx.doi.org/10.1016/j.tifs.2011.12.007

Barbut, S. (2015). *The science of poultry and meat processing*. Guelph: University of Guelph. Battering and breading – production under HACCP, pp. 14-1-14-50.

Barros, J. C., Gois, T. S., Pires, M. A., Rodrigues, I., & Trindade, M. A. (2019a). Sodium reduction in enrobed restructured chicken nuggets through replacement of NaCl with $CaCl_2$. *Journal of Food Science and Technology*, *56*(8), 3587-3596. PMid:31413386. http://dx.doi.org/10.1007/s13197-019-03777-8

Barros, J. C., Munekata, P. E. S., Carvalho, F. A. L., Domínguez, R., Trindade, M. A., Pateiro, M., & Lorenzo, J. M. (2021). Healthy beef burgers: Effect of animal fat replacement by algal and wheat germ oil emulsions. *Meat Science*, *173*, 108396. PMid:33288362. http://dx.doi.org/10.1016/j.meatsci.2020.108396

Barros, J. C., Munekata, P. E. S., Carvalho, F. A. L., Pateiro, M., Barba, F. J., Domínguez, R., Trindade, M. A., & Lorenzo, J. M. (2020). Use of tiger nut (C*yperus esculentus* l.) oil emulsion as animal fat replacement in beef burgers. *Foods*, *9*(1), 44. PMid:31947797. http://dx.doi.org/10.3390/foods9010044

Barros, J. C., Munekata, P. E. S., Pires, M. A., Rodrigues, I., Andaloussi, O. S., Rodrigues, C. E. C., & Trindade, M. A. (2018). Omega-3- and fibre-enriched chicken nuggets by replacement of chicken skin with chia (*Salvia hispanica* L.) flour. *Lebensmittel-Wissenschaft + Technologie*, *90*, 283-289. http://dx.doi.org/10.1016/j.lwt.2017.12.041

Barros, J. C., Rodrigues, I., Pires, M. A., Gonçalves, L. A., Carvalho, F. A. L., & Trindade, M. A. (2019b). Healthier chicken nuggets incorporated with chia (*Salvia hispanica* L.) flour and partial replacement of sodium chloride with calcium chloride. *Emirates Journal of Food and Agriculture*, *31*(10), 794-803. http://dx.doi.org/10.9755/ejfa.2019.v31.i10.2021

Bernardi, D. M., Bertol, T. M., Pflanzer, S. B., Sgarbieri, V. C., & Pollonio, M. A. R. (2016). ω-3 in meat products: Benefits and effects on lipid oxidative stability. *Journal of the Science of Food and Agriculture*, *96*(8), 2620-2634. PMid:26676414. http://dx.doi.org/10.1002/jsfa.7559

Bernaud, F. S. R., & Rodrigues, T. C. (2013). Fibra alimentar – ingestão adequada e efeitos sobre a saúde do metabolismo. *Arquivos Brasileiros de Endocrinologia & Metabologia*, *57*(6), 397-405. http://dx.doi.org/10.1590/S0004-27302013000600001

Brasil. Agência Nacional de Vigilância Sanitária. (2003, December 26). Regulamento Técnico Sobre Rotulagem Nutricional de Alimentos Embalados (Resolução RDC nº 360, de 23 de dezembro de 2003). *Diário Oficial [da] República Federativa do Brasil*, Brasília, seção 1.

Brasil. Agência Nacional de Vigilância Sanitária. (2005, September 23). Aprova o “Regulamento Técnico Sobre a Ingestão Diária Recomendada (IDR) de Proteína, Vitaminas e Minerais” (Resolução RDC nº 269, de 22 de setembro de 2005). *Diário Oficial [da] República Federativa do Brasil*, Brasília, seção 1.

Brasil. Agência Nacional de Vigilância Sanitária. (2012, November 12). Dispõe sobre o Regulamento Técnico sobre Informação Nutricional Complementar (Resolução RDC nº 54, de 12 de novembro de 2012). *Diário Oficial [da] República Federativa do Brasil*, Brasília, seção 1.

Carvalho, L. R. S., Silva, C. H. D., & Giada, M. L. R. (2018). Physical, chemical and sensorial properties of low-fat and gluten-free chicken nuggets. *Journal of Culinary Science & Technology*, *16*(1), 18-29. http://dx.doi.org/10.1080/15428052.2017.1310071

Chayawat, J., & Rumpagaporn, P. (2020). Reducing chicken nugget oil content with fortified defatted rice bran in bater. *Food Science and Biotechnology*, *29*(10), 1355-1363. PMid:32999742. http://dx.doi.org/10.1007/s10068-020-00782-y

Choe, J. H., Kim, H. Y., Lee, J. M., Kim, Y. J., & Kim, C. J. (2013). Quality of frankfurter-type sausages with added pig skin and wheat fiber mixture as fat replacers. *Meat Science*, *93*(4), 849-854. PMid:23313971. http://dx.doi.org/10.1016/j.meatsci.2012.11.054

Cornell University. (2006, March 16). *Robert C. Baker, creator of chicken nuggets and Cornell chicken barbecue sauce, dies at 84*. Retrieved in 2018, April 28, from http://news.cornell.edu/stories/2006/03/food-and-poultry-scientist-robert-c-baker-dies-age-84

Dana, D., & Saguy, I. S. (2006). Review: Mechanism of oil uptake during deep-fat frying and the surfactant effect-theory and myth. *Advances in Colloid and Interface Science*, *128-130*, 267-272. PMid:17196541. http://dx.doi.org/10.1016/j.cis.2006.11.013

Dourado, C., Pinto, C., Barba, F. J., Lorenzo, J. M., Delgadillo, I., & Saraiva, J. A. (2019). Innovative non-thermal technologies affecting potato tuber and fried potato quality. *Trends in Food Science & Technology*, *88*, 274-289. http://dx.doi.org/10.1016/j.tifs.2019.03.015

Elleuch, M., Bedigian, D., Roiseux, O., Besbes, S., Blecker, C., & Attia, H. (2011). Dietary fibre and fibre-rich by-products of food processing: Characterisation, technological functionality and commercial applications: A review. *Food Chemistry*, *124*(2), 411-421. http://dx.doi.org/10.1016/j.foodchem.2010.06.077

European Union – EU. (2010). Commission Regulation (EU) nº 116/2010 of 9 February 2010 amending Regulation (EC) nº 1924/2006 of the European Parliament and of the Council with regard to the list of nutrition claims. *Official Journal of the European Union*, Brussels.

Food Standards Agency – FSA. (2016). *National Diet and Nutrition Survey: Assessment of dietary sodium*. Retrieved in 2018, April 14, from https://www.gov.uk/government/statistics/national-diet-and-nutrition-survey-assessment-of-salt-intake-from-urinary-sodium-in-adults-aged-19-to-64-years-in-england-2018-to-2019

Horita, C. N., Messias, V. C., Morgano, M. A., Hayakawa, F. M., & Pollonio, M. A. R. (2014). Textural, microstructural and sensory properties of reduced sodium frankfurter sausages containing mechanically deboned poultry meat and blends of chloride salts. *Food Research International*, *66*, 29-35. http://dx.doi.org/10.1016/j.foodres.2014.09.002

Horita, C. N., Morgano, M. A., Celeghini, R. M. S., & Pollonio, M. A. R. (2011). Physico-chemical and sensory properties of reduced-fat mortadella prepared with blends of calcium, magnesium and potassium chloride as partial substitutes for sodium chloride. *Meat Science*, *89*(4), 426-433. PMid:21645975. http://dx.doi.org/10.1016/j.meatsci.2011.05.010

Inguglia, E. S., Zhang, Z., Tiwari, B. K., Kerry, J. P., & Burgess, C. M. (2017). Salt reduction strategies in processed meat products – a review. *Trends in Food Science & Technology*, *59*, 70-78. http://dx.doi.org/10.1016/j.tifs.2016.10.016

Jiménez-Colmenero, F. (2007). Healthier lipid formulation approaches in meatbased functional foods. Technological options for replacement of meat fats by non-meat fats. *Trends in Food Science & Technology*, *18*(11), 567-578. http://dx.doi.org/10.1016/j.tifs.2007.05.006

Kumcuoglu, S., & Cagdas, E. (2015). Effects of grape seed powder and whey protein on quality characteristics of chicken nuggets. *Journal of Food Quality*, *38*(2), 83-93. http://dx.doi.org/10.1111/jfq.12131

Kurek, M., Ščetar, M., & Galić, K. (2017). Edible coatings minimize fat uptake in deep fat fried products: A review. *Food Hydrocolloids*, *71*, 225-235. http://dx.doi.org/10.1016/j.foodhyd.2017.05.006

Liberty, J. T., Dehghannya, J., & Ngadi, M. O. (2019). Effective strategies for reduction of oil content in deep-fat fried foods: A review. *Trends in Food Science & Technology*, *92*, 172-183. http://dx.doi.org/10.1016/j.tifs.2019.07.050

Lorenzo, J. M., Munekata, P. E. S., Pateiro, M., Campagnol, P. C. B., & Domínguez, R. (2016). Healthy Spanish salchichón enriched with encapsulated n-3 long chain fatty acids in konjac glucomannan matrix. *Food Research International*, *89*(Pt 1), 289-295. PMid:28460917. http://dx.doi.org/10.1016/j.foodres.2016.08.012

Martelli, M. R., Carvalho, R. A., Sobral, P. J. A., & Santos, J. S. (2008). Reduction of oil uptake in deep fat fried chicken nuggets using edible coatings based on cassava starch and methylcellulose. *Italian Journal of Food Science*, *20*(1), 111-117.

Oztop, M. H., Bansal, H., Takhar, P., McCarthy, K. L., & McCarthy, M. J. (2014). Using multi-slice-multi-echo images with NMR relaxometry to assess water and fat distribution in coated chicken nuggets. *Lebensmittel-Wissenschaft + Technologie*, *55*(2), 690-694. http://dx.doi.org/10.1016/j.lwt.2013.10.031

Pérez-Palacios, T., Ruiz-Carrascal, J., Jiménez-Martín, E., Solomando, J. C., & Antequera, T. (2018). Improving the lipid profile of ready-to-cook meat products by addition of omega-3 microcapsules: Effect on oxidation and sensory analysis. *Journal of the Science of Food and Agriculture*, *98*(14), 5302-5312. PMid:29656385. http://dx.doi.org/10.1002/jsfa.9069

Rangel-Vargas, E., Rodriguez, J. A., Domínguez, R., Lorenzo, J. M., Sosa, M. E., Andrés, S. C., Rosmini, M., Pérez-Alvarez, J. A., Teixeira, A., & Santos, E. M. (2021). Edible mushrooms as a natural source of food ingredient/additive replacer. *Foods*, *10*(11), 2687. PMid:34828969. http://dx.doi.org/10.3390/foods10112687

Rios-Mera, J. D., Saldaña, E., Patinho, I., Selani, M. M., & Contreras-Castillo, C. J. (2021). Advances and gaps in studies on healthy meat products and their relationship with regulations: The Brazilian scenario. *Trends in Food Science & Technology*, *110*, 833-840. http://dx.doi.org/10.1016/j.tifs.2021.01.092

Rodrigues, I., Baldini, A., Pires, M., Barros, J. C., Fregonesi, R., Lima, C. G., & Trindade, M. A. (2021). Gamma ray irradiation: A new strategy to increase the shelf life of salt-reduced hot dog wieners. *Lebensmittel-Wissenschaft + Technologie*, *135*, 110265. http://dx.doi.org/10.1016/j.lwt.2020.110265

Rosamond, W. D. (2002). Dietary fiber and prevention of cardiovascular disease. *Journal of the American College of Cardiology*, *39*(1), 57-59. PMid:11755287. http://dx.doi.org/10.1016/S0735-1097(01)01685-0

Ruusunen, M., & Puolanne, E. (2005). Reducing sodium intake from meat products. *Meat Science*, *70*(3), 531-541. PMid:22063751. http://dx.doi.org/10.1016/j.meatsci.2004.07.016

Sahin, S., Sumnu, G., & Altunakar, B. (2005). Effects of batters containing different gum types on the quality of deep-fat fried chicken nuggets. *Journal of the Science of Food and Agriculture*, *85*(14), 2375-2379. http://dx.doi.org/10.1002/jsfa.2258

Santhi, D., & Kalaikannan, A. (2014). The effect of the addition of oat flour in low-fat chicken nuggets. *Journal of Nutrition & Food Sciences*, *4*, 1-4.

Santos, B. A., Campagnol, P. C. B., Fagundes, M. B., Wagner, R., & Pollonio, M. A. R. (2017). Adding blends of NaCl, KCl, and $CaCl_2$ to low-sodium dry fermented sausages: Effects on lipid oxidation on curing process and shelf life. *Journal of Food Quality*, *2017*, 7085798. http://dx.doi.org/10.1155/2017/7085798

Segura-Campos, M. R., Ciau-Solís, N., Rosado-Rubio, G., Chel-Guerrero, L., & Betancur-Ancona, D. (2014). Physicochemical characterization of chia (*Salvia hispanica*) seed oil from Yucatán, México. *Agricultural Sciences*, *5*(3), 220-226. http://dx.doi.org/10.4236/as.2014.53025

Shahidi, F., & Ambigaipalan, P. (2018). Omega-3 polyunsaturated fatty acids and their health benefits. *Annual Review of Food Science and Technology*, *9*(1), 345-381. PMid:29350557. http://dx.doi.org/10.1146/annurev-food-111317-095850

Simopoulos, A. P. (2016). An increase in the omega-6/omega-3 fatty acid ratio increases the risk for obesity. *Nutrients*, *8*(3), 128. PMid:26950145. http://dx.doi.org/10.3390/nu8030128

Slavin, J. L. (2008). Position of the American Dietetic Association: Health implications of dietary fiber. *Journal of the American Dietetic Association*, *108*(10), 1716-1731. PMid:18953766. http://dx.doi.org/10.1016/j.jada.2008.08.007

Trumbo, P., Schlicker, S., Yates, A. A., & Poos, M. (2002). Dietary reference intakes for energy, carbohydrate, fiber, fat, fatty acids, cholesterol, protein and amino acids. *Journal of the American Dietetic Association*, *102*(11), 1621-1630. PMid:12449285. http://dx.doi.org/10.1016/S0002-8223(02)90346-9

Varela, P., & Fiszman, S. M. (2011). Hydrocolloids in fried foods. A review. *Food Hydrocolloids*, *25*(8), 1801-1812. http://dx.doi.org/10.1016/j.foodhyd.2011.01.016

Verdú, S., Barat, J. M., & Grau, R. (2017). Improving bread-making processing phases of fibre-rich formulas using chia (Salvia hispanica) seed flour. *Lebensmittel-Wissenschaft + Technologie*, *84*, 419-425. http://dx.doi.org/10.1016/j.lwt.2017.06.007

Verma, A. K., & Banerjee, R. (2010). Dietary fibre as functional ingredient in meat products: a novel approach for healthy living – a review. *Journal of Food Science and Technology*, *47*(3), 247-257. PMid:23572633. http://dx.doi.org/10.1007/s13197-010-0039-8

Verma, A. K., Banerjee, R., & Sharma, B. D. (2012). Quality of low fat chicken nuggets: Effect of sodium chloride replacement and added chickpea (Cicer arietinum L.) hull flour. *Asian-Australasian Journal of Animal Sciences*, *25*(2), 291-298. PMid:25049565. http://dx.doi.org/10.5713/ajas.2011.11263

Verma, A. K., Banerjee, R., & Sharma, B. D. (2015). Quality characteristics of low fat chicken nuggets: Effect of salt substitute blend and pea hull flour. *Journal of Food Science and Technology*, *52*(4), 2288-2295. PMid:25829611. http://dx.doi.org/10.1007/s13197-013-1218-1

World Health Organization – WHO. (2013). *Mapping salt reduction initiatives in the WHO European Region*. Retrieved in 2018, April 19, from https://apps.who.int/iris/bitstream/handle/10665/365639/9789289000178-eng.pdf?sequence=1&isAllowed=y

Yang, H. H. L., & Lawless, H. T. (2005). Descriptive analysis of divalent salts. *Journal of sensory studies*, *20*(2), 97-113. PMid:16614749. http://dx.doi.org/10.1111/j.1745-459X.2005.00005.x

Yashodhara, B. M., Umakanth, S., Pappachan, J. M., Bhat, S. K., Kamath, R., & Choo, B. H. (2009). Omega-3 fatty acids: A comprehensive review of their role in health and disease. *Postgraduate Medical Journal*, *85*(1000), 84-90. PMid:19329703. http://dx.doi.org/10.1136/pgmj.2008.073338

Yogesh, K., Ahmad, T., Manpreet, G., Mangesh, K., & Das, P. (2013). Characteristics of chicken nuggets as affected by added fat and variable salt contents. *Journal of Food Science and Technology*, *50*(1), 191-196. PMid:24425908. http://dx.doi.org/10.1007/s13197-012-0617-z

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