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REDUÇÃO DE SÓDIO EM PRODUTOS CÁRNEOS COM ATIVIDADE DE ÁGUA INTERMEDIÁRIA E SORÇÃO DE ÁGUA: CASO DA COPA

São José do Rio Preto
2024

EDUARDO OLIVEIRA IGNÁCIO

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Tese apresentada como parte dos requisitos para obtenção do título de Doutor em Engenharia e Ciência de Alimentos, junto ao Programa de Pós-graduação em Engenharia e Ciência de Alimentos (Área de concentração: Ciência e Tecnologia de Alimentos) do Instituto de Biociências, Letras e Ciências Exatas da Universidade Estadual Paulista "Júlio de Mesquita Filho", Campus de São José do Rio Preto.

Orientadora: Profª. Dra. Andrea Carla da Silva Barretto

Coorientador: Prof. Dr. Javier Telis Romero

São José do Rio Preto

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Dedicatória

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RESUMO

Esta tese investigou algumas estratégias no desafio de produzir carne curada com redução de sódio, diante da crescente demanda por alimentos mais saudáveis e da preocupação com os impactos do consumo excessivo de sódio na saúde, especialmente relacionados a doenças cardiovasculares e hipertensão. A estrutura foi dividida em capítulos para propiciar uma organização lógica e coerente do conteúdo, otimizando a compreensão e facilitando o processo de revisão e correção, além de possibilitar a publicação de partes da pesquisa como artigos científicos independentes, amplificando a visibilidade do trabalho no âmbito acadêmico. O estudo iniciou com uma revisão de literatura sobre as estratégias e os desafios de se reduzir o teor de sódio em produtos cárneos com atividade de água intermediária. Na sequência, avaliou-se o efeito da substituição parcial de NaCl por KCl e CaCl2 em copa seca e curada nas propriedades físico-químicas e aceitação sensorial. Foram realizados cinco tratamentos: Controle (CON) com 100% de NaCl; “25K” com redução de 25% de NaCl e adição de 25% de KCl; “25KCa” com redução de 25% de NaCl, adição de 15% de KCl e 10% de CaCl2; “50K” com redução de 50% de NaCl e adição de 50% de KCl; e “50KCa” com redução de 50% de NaCl e adição de 25% de KCl e 25% de CaCl2. Observou-se que a redução de até 50% não afetou a aceitabilidade global, sendo a substituição parcial do NaCl uma alternativa viável. Por fim, a pesquisa examinou a composição química e as isotermas de sorção de oito copas comerciais em diferentes temperaturas (5, 10, 20, 30 e 40°C). As informações sobre o comportamento das copas comerciais em relação à umidade podem auxiliar na tomada de decisões relacionadas ao armazenamento, embalagem e controle de qualidade. Foram observadas diferenças na composição química, e as isotermas de sorção foram classificadas como tipo II, exibindo um comportamento sigmoidal. O modelo matemático GAB apresentou o melhor ajuste aos dados experimentais ($R^2adj \geq 0{,}99$, $\chi^2 \leq 3{,}84.10^{-4}$ e REQM $\leq 0{,}02$). O teor de umidade da monocamada (X_m) diminuiu com o aumento da temperatura. Os resultados obtidos, em geral, apresentaram contribuições para a indústria de alimentos, sugerindo métodos para desenvolver carnes curadas mais saudáveis, que alinham a produção às preocupações contemporâneas de saúde pública, sem comprometer as características desejadas pelos consumidores.

Palavras-chave: Produtos mais saudáveis, tecnologias inovadoras, aceitação do consumidor e umidade de equilíbrio.

ABSTRACT

This thesis investigated strategies for producing cured meat with reduced sodium content, addressing the growing demand for healthier foods and concerns about the impacts of excessive sodium consumption on health, particularly related to cardiovascular diseases and hypertension. The structure was divided into chapters to provide a logical and coherent organization of the content, optimizing comprehension and facilitating the review and correction process, as well as enabling the publication of parts of the research as independent scientific articles, amplifying the visibility of the work in the academic sphere. The study began with a literature review on strategies and challenges in reducing sodium content in meat products with intermediate water activity. Subsequently, the effect of partial substitution of NaCl with KCl and CaCl2 on the physicochemical properties and sensory acceptance of dry-cured coppa was evaluated. Five treatments were performed: Control (CON) with 100% NaCl; “25K” with a 25% reduction in NaCl and addition of 25% KCl; “25KCa” with a 25% reduction in NaCl, addition of 15% KCl, and 10% CaCl2; “50K” with a 50% reduction in NaCl and addition of 50% KCl; and “50KCa” with a 50% reduction in NaCl and addition of 25% KCl and 25% CaCl2. It was observed that a reduction of up to 50% did not affect overall acceptability, indicating that partial substitution of NaCl is a viable alternative. Finally, the research examined the chemical composition and sorption isotherms of eight commercial coppas at different temperatures (5, 10, 20, 30, and 40°C). Information on the behavior of commercial coppas in relation to moisture can assist in decision-making related to storage, packaging, and quality control. Differences in chemical composition were observed, and the sorption isotherms were classified as type II, exhibiting sigmoidal behavior. The GAB mathematical model presented the best fit to the experimental data ($R^2adj \geq 0.99$, $\chi^2 \leq 3.84.10^{-4}$, and RMSE ≤ 0.02). The monolayer moisture content (X_m) decreased with increasing temperature. The results obtained, in general, presented contributions to the food industry, suggesting methods for developing healthier cured meat products that align production with contemporary public health concerns without compromising the characteristics desired by consumers.

Keywords: Healthier products, innovative technologies, consumer acceptance, and equilibrium moisture content.

LISTA DE FIGURAS

LISTA DE TABELAS

SUMÁRIO

INTRODUÇÃO GERAL

Atualmente, o avanço tecnológico, impulsionado pela crescente preocupação da sociedade e dos governos com a promoção de uma alimentação mais saudável, tem despertado o interesse de pesquisadores em iniciativas para reduzir o teor de cloreto de sódio (NaCl) em produtos alimentícios. Ao longo dos anos, a Organização Mundial da Saúde (OMS) vem continuamente emitindo documentos que abordam a questão do consumo excessivo de sódio e seus impactos na saúde. Em 2012, foi publicada a diretriz "Ingestão de Sódio para Adultos e Crianças (OMS, 2012), estabelecendo recomendações claras sobre os limites de ingestão diária de sódio. Em um esforço para conscientização sobre a importância da redução de sódio vem lançando constantemente recomendações ao longo do tempo, e em 2021, divulgou o guia "Referências Globais da OMS para o Sódio em Diferentes Categorias de Alimentos" (OMS, 2021), com o objetivo de auxiliar os países na redução do teor de sódio em alimentos processados.

Esses documentos demonstram o compromisso contínuo da OMS em alertar sobre o consumo excessivo de NaCl e reitera a associação entre a quantidade de sódio ingerida e o aumento da pressão arterial, resultando em maior risco de doenças cardiovasculares, as quais respondem por 32% das mortes relacionadas à doenças crônicas não transmissíveis em escala global (Ruusunen & Puolanne, 2005; Schivazappa & Virgili, 2020)

O NaCl desempenha um papel fundamental como conservante em alimentos por ajuda na redução da atividade de água. Apesar dos avanços nos sistemas de refrigeração que possibilitaram uma redução no uso de conservantes, o NaCl ainda é amplamente utilizado no processamento de alimentos (Inguglia et al., 2017). Além de aumentar a vida útil dos produtos, o sal tem importantes funções sensoriais, como melhorar o sabor, aroma e textura dos alimentos (Desmond, 2006).

Estudos realizados em contextos internacionais indicaram que aproximadamente 77% do sódio consumido pelos indivíduos é proveniente do sal adicionado durante a produção industrial de alimentos, enquanto 12% está naturalmente presente nos alimentos e 11% é adicionado durante o preparo ou consumo (Aaslyng et al., 2014; Inguglia et al., 2017). Entre os grupos de produtos industrializados, as principais fontes de sódio são as carnes processadas (18%), pães e produtos de panificação (13%), laticínios (12%) e molhos e pastas (11%).

A ingestão elevada de sódio tem impacto significativo na pressão arterial dos indivíduos, e a Organização Mundial da Saúde tem recomendado a limitação da ingestão de NaCl a até 5g por dia, visando a redução da incidência de hipertensão, doenças cardíacas e acidentes vasculares cerebrais (Aliño et al., 2010; Armenteros et al., 2012; WHO, 2012).

Na indústria de produtos cárneos, o NaCl desempenha múltiplos papéis, sendo utilizado para realçar o sabor, agir como agente bacteriostático e conferir a textura desejada aos produtos. Além disso, suas propriedades funcionais são responsáveis por várias funções importantes, tais como a solubilização de proteínas, que aumenta a hidratação e a capacidade de retenção de água, bem como melhora a capacidade de ligação das proteínas para aprimorar a textura. O NaCl também aumenta a viscosidade da massa cárnea e melhora a capacidade de emulsificação com a incorporação de gorduras (Desmond, 2006).

A redução NaCl tem se mostrado um desafio significativo para a indústria de produtos cárneos, principalmente por ser um dos ingredientes mais acessíveis economicamente, e sua substituição implicaria em aumento nos custos de produção. Diversas estratégias têm sido propostas para enfrentar esse desafio, incluindo: (i) a redução do NaCl com base na aceitação sensorial do consumidor e/ou a substituição parcial por outro sal ou mistura de sais, sendo o cloreto de potássio (KCl) o mais comumente utilizado, embora também sejam empregados cloreto de cálcio ($CaCl_2$) e cloreto de magnésio ($MgCl_2$); (ii) o uso de realçadores de sabor que não possuem gosto salgado, como o glutamato monossódico e o extrato de levedura; (iii) a modificação da forma física do NaCl para torná-lo mais disponível; e (iv) o aumento da difusão do NaCl utilizando pressão ou ultrassom (Desmond, 2006; Inguglia et al., 2017). Em produtos cárneos com atividade de água intermediária, a atividade de água varia entre 0,60 e 0,85. Esses produtos possuem menos água livre quando comparados a alimentos frescos e mais perecíveis, e são consumidos sem reidratação. Assim, a redução de sódio se contradiz com o suporte tecnológico que este ingrediente traz, auxiliando na redução da atividade de água e também na perda de peso ao longo do período de secagem, além de influenciar no aspecto sensorial.

APRESENTAÇÃO DO TRABALHO

O presente projeto foi dividido em três seções com o objetivo de promover uma apresentação mais eficiente e uma compreensão mais clara dos tópicos discutidos.

O Capítulo 1 trata-se de uma revisão bibliográfica sobre o tema de interesse abordados na tese. A revisão intitulada de "Processing Challenges and Strategies for Low-Sodium Dry-Cured Meat: An Overview" onde o levantamento bibliográfico fala sobre os desafios e as estratégias para redução de sódio em produtos cárneos com atividade de água intermediaria. Este capítulo será submetido à Revista Scientia Agricola.

O Capítulo 2 trata-se do artigo científico "Impact of NaCl Partial Replacement by KCl and $CaCl_2$ on Physicochemical Properties and Sensorial Preference of Dry-Cured *Coppa.*" Que avaliaou o efeito da adição de KCl e $CaCl_2$ à copa curada seca, com redução de NaCl, sobre suas propriedades físico-químicas e aceitação sensorial. Foram testados diferentes tratamentos onde investigou-se como essas substâncias afetam a textura, cor e aceitação global do produto Este capítulo foi submetido à Revista Scientia Agricola.

O Capítulo 3 trata-se do artigo "Influence of temperature and chemical composition on water sorption isothermes for dry-cured *Coppa*". Este capítulo explora o efeito da temperatura e da composição química na sorção de água em copa curada seca, como objetivo de compreender melhor como fatores a temperatura de armazenamento e a composição química influenciam a estabilidade do produto e sua capacidade de reter água durante o armazenamento. Este capítulo foi submetido no periódico *Journal of Food Process Engineering*

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OBJETIVOS

a. Objetivo Geral

Este estudo teve por objetivo geral avaliar realizar uma revisão de literatura sobre redução de sódio em produtos cárneos e avaliar os efeitos da redução de sódio nas propriedades físico-químicas, como cor e oxidação lipídica, e nas propriedades sensoriais de um produto cárneo curado com intermediária atividade de água denominado copa. Além disso, investigou-se como a variação da composição química, especialmente em relação ao teor de NaCl, de diferentes amostras de copas comerciais encontradas em supermercados locais e sua influência nas isotermas de sorção de água em diferentes temperaturas de armazenamento.

b. Objetivos Específicos

- ✓ Estudar o impacto na redução de sódio em formulações de copa;
- ✓ Adicionar KCl e $CaCl_2$ como sais substitutos ao NaCl em diferentes níveis de substituição;
- ✓ Avaliar os possíveis efeitos da substituição do NaCl nas propriedades físico-químicas
- ✓ Avaliar a aceitação sensorial de diferentes formulações de copa;
- ✓ Avaliar a influência da composição química na sorção de água de oito marcas comerciais de copa, em diferentes temperaturas de armazenamento;
- ✓ Investigar se o conteúdo de NaCl afeta as isotermas de sorção.

Capítulo 1

PROCESSING CHALLENGES AND STRATEGIES FOR LOW-SODIUM DRY-CURED MEAT: AN OVERVIEW

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Processing Challenges and Strategies for Low-Sodium Dry-Cured Meat: An Overview

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Abstract

Meat plays a crucial role in the global diet as a primary source of high-quality protein, essential amino acids, and vital nutrients. Despite its nutritional benefits, the perception of meat as unhealthy due to its fat and salt content poses a challenge. Addressing these concerns, particularly in the context of pork the most consumed meat globally offers an opportunity to make meat more attractive to health-conscious consumers. Innovating production processes to reduce sodium and improve the nutritional profile without compromising taste or safety can align meat products with healthier consumer preferences. Curing meat adds distinct flavors and colors while controlling microbial growth by reducing water activity. Yet, this process increases sodium content, conflicting with health guidelines to reduce sodium intake due to its links to cardiovascular diseases and hypertension. The World Health Organization (WHO) recommends lowering sodium consumption to address these health risks, highlighting the significant role of processed meats in the global high sodium intake and the urgent need for sodium reduction strategies in processed foods. The future of cured meat production is being shaped by a series of innovative approaches aimed at overcoming the challenges of reducing sodium content, shortening curing times, and enhancing sustainability. These include the exploration of non-invasive technologies such as X-ray and magnetic resonance imaging for precise maturation assessments, the nuanced understanding of salt's differential solubility in lean versus fatty tissues for optimal curing, and the shift towards natural alternatives to traditional curing agents in response to consumer demand for cleaner labeling. Furthermore, emerging technologies like the encapsulation of

sodium nitrate and nitrite, nanotechnology for food reformulation, sensory contrast technology, and data mining techniques offer promising strategies for maintaining product quality and safety while reducing undesirable ingredients.

Keywords: Salt reduction, low sodium, Dry-cured meat.

1. Introduction

The production and consumption of meat have increased worldwide due to globalization (Flores & Toldrá, 2021). Modern society considers meat and meat-derived products as the main source of protein in the omnivorous diet. Being a nutrient-dense food, its balanced inclusion in a diet ensures the supply of amino acids, vitamins, and minerals, with notable presence of vitamins B6, B12, zinc, and iron (Fraqueza et al., 2018). Nevertheless, consumers often associate meat products with potentially unhealthy foods, owing to nutritional characteristics such as recognized levels of fat and salt (Fraqueza et al., 2018; Grasso et al., 2014)

Pork is the most consumed meat in the world, with Brazilian pork production reaching 4.7 million tons in 2021 and per capita consumption reaching 16.7 kg/hab. From this entire production, which is sold to 86 countries, pork products represent only 0.77% of the amount exported (ABPA, 2023). Figures such as these exemplify the considerable presence of pork-based meat products in both domestic consumption and Brazilian exports. This significance is particularly notable when considering the potential alignment of production practices with consumer demand for healthier meat options. Leal-Ramos et al. (2011) have already pointed out that all over the world, people are becoming more aware of the relationship between health, nutrition and food.

In Brazil, approximately 70% of pork consumption is concentrated in processed products, such as salami, ham, sausages, and mortadella, rather than fresh products. However, dry-cured products, such as coppa, are recognized as niche products aimed at the high-end market and account for only 0.4% of the processed pork market (de Andrade et al., 2018). Nevertheless, the manufacturing process of these products often results in a significant increase in sodium content, primarily through the addition of NaCl, which is a common practice to enhance flavor, improve texture, inhibit microbial growth, and retain moisture. This increase in sodium content, although beneficial for the sensory properties and food safety, contrasts with global health recommendations, which warn about the risks associated with excessive sodium consumption, including various chronic diseases such as cardiovascular diseases, hypertension, among others (Ma et al., 2024).

Cured meat products are clearly defined by the addition of NaCl, nitrate and/or nitrite, which are commonly referred to as 'curing' agents in the industry. These agents unequivocally provide the distinctive properties that are universally common to all cured products (Sebranek & Bacus, 2007). Dry-cured meat products are composed mainly of muscular tissue that has undergone a transformation in its surface physicochemical properties, resulting in a low water activity (a_w) due to the high salt content. This effectively controls the microbial population that would develop on the outer portion of the products (Pizzolato Montanha et al., 2018; Toldra, 2014).

Curing, or salting, as it is known today, is one of the oldest methods of preserving food, dating back to the 3,000's. The curing or salting process is used to add flavor and color to meat products (Lonergan et al., 2019; Ramanathan et al., 2020).The curing process dehydrated the meat and prevented bacterial growth by applying a high concentration of NaCl to the surface of the meat to reduce water activity to a level that is unacceptable to the microorganisms that cause spoilage (Feiner, 2006).

During the meat drying process, two simultaneous and opposing mass transfer phenomena occur: the gradual release of water from the internal to the external spaces of the myofibrils, and the absorption of salt into the muscle tissue. This results in lower moisture and higher sodium contents in the final product (Vidal et al., 2019).

The drying process of meat products is an ancient technique, essential in preserving and developing the unique sensory characteristics of these foods. This practice, the subject of extensive study and refinement throughout history, involves the controlled removal of water from muscle tissue, lowering the water activity to levels that prevent the growth of pathogenic and spoilage microorganisms (Pravallika et al., 2023). Drying emerges as a critical process parameter, significantly influenced by the food matrix, which directly affects the preparation time and, consequently, the costs associated with meat products with intermediate water activity (between 0.65 and 0.90). Factors such as temperature, relative humidity, and air circulation speed are rigorously controlled to ensure food quality and safety, as well as to preserve or enhance the sensory properties of the products. The academic field continues to explore this area, not only seeking to improve drying methods to increase efficiency and quality but also investigating innovative technologies and strategies to reduce environmental impact and meet the demands of an increasingly informed and discerning consumer market.

Drying methods, essential for the preservation and enhancement of various product properties, vary widely and are categorized based on criteria such as the type of heating, the heat transfer medium, and the heat application method. Among traditional techniques, natural drying, air drying, hot air drying, freeze-drying, and vacuum drying stand out, each with its own set of specific advantages and drawbacks. The selection of a drying method is largely dependent on the product type and the desired outcome. Taking the drying process used in coppa production as an example, this method, one of the oldest and most natural, eschews artificial heat sources, relying instead on environmental conditions like temperature and humidity to gradually remove moisture from the product (Kong et al., 2023).

NaCl is a major contributor to high dietary sodium intake, which is strongly associated with elevated blood pressure and negative cardiovascular outcomes. It is clear that reducing sodium intake is a crucial step in improving cardiovascular health (Jia et al., 2024). The increase in blood pressure stands as a primary contributor to cardiovascular disease, accounting for 62% of strokes and 49% of coronary diseases (He & MacGregor, 2010). The harmful impact of sodium intake on blood pressure has been consistently demonstrated through animal studies, epidemiological research, and clinical trials, affecting both hypertensive and normotensive individuals. Excessive sodium consumption directly causes coronary heart disease, stroke, and non-cardiovascular ailments (Brown et al., 2009).

In 2012, the World Health Organization (WHO) already issued a strong recommendation for reducing sodium intake to lower blood pressure and mitigate the risk of cardiovascular diseases, stroke, and coronary heart disease in adults. WHO advocates for reducing sodium intake to less than 2 grams per day of sodium (equivalent to 5 grams per day of salt) in adults(WHO, 2012). There is overwhelming evidence indicating that dietary salt is the primary factor driving elevated blood pressure and that reducing salt intake lowers blood pressure, consequently reducing salt-related diseases (He & MacGregor, 2010).

In their study, Jia et al. (2024) explored the sodium content in raw meats compared to processed meat products, uncovering a substantial disparity in sodium levels present. The sodium content in raw meat samples, such as beef, pork, chicken, and turkey, ranged from 27 mg to 60 mg per 100 g, showcasing a relatively low level of naturally occurring sodium. Conversely, processed products demonstrated a significant increase in sodium levels. For instance, sausages exhibited sodium contents ranging from 376 mg to 1420 mg per 100 g, depending on the country of origin, while ham and bacon's sodium levels could reach up to 2000 mg per 100 g.

The consumption of processed food products, including processed meats, is a significant contributor to the high sodium intake in many regions, including Europe, North America, and Australia, accounting for about 77% of the total salt consumption, with processed meats contributing approximately 16.3%. This trend exceeds the intake limits recommended by the WHO, highlighting the urgent need for effective strategies to reduce the sodium content in processed foods (Ma et al., 2024).

2. Meat products with intermediate water activity

Dry-cured meats are characterized by their intermediate water activity (a_w) and high salt concentrations (Sonjak et al., 2011). Dry-cured meat products can exhibit NaCl content of up to 8%, with variations depending on the curing time to which they are subjected. Differences within the same product category are observed, associated with the specificities of each company's formulations. This variation is primarily because the market contains several classifications within a single category, which also changes according to the country and/or region due to cultural habits (Desmond, 2006).

NaCl plays a vital role in the preservation process by reducing the water content raising the osmotic pressure, thus inhibiting microbial growth. It is also essential for improving flavor, texture, stability and guaranteeing the overall quality and safety of cured meats (Domenico et al., 2021), given its role, NaCl is, therefore, the most important functional ingredient (Feiner, 2006). Dry-curing meat is a multi-stage process that involves salting and curing with NaCl and other additives. The meat then rests in a refrigerated environment at temperatures below 5°C until the water activity (a_w) decreases below 0.96, which limits the growth of undesirable microorganisms. The final stage is drying, during which the water activity decreases, and the characteristic matured flavor develops more quickly (Arnau et al., 2007).

Product safety is closely related to water activity, with lower water activity corresponding to longer shelf life. Li et al. (2023) cite jerky beef as an example, considered safe under aerobic conditions with a water activity of less than 0.85 because this inhibits microbial growth. The water activity of dry meat products, such as dry sausage or dry-cured ham, is correspondingly lower due to their higher salt content, with values typically ranging from 0.92 to 0.80 (Petričević et al., 2018).

According to Prabhakar (2014), these products can be categorized as products with intermediate water activity, products moist enough to be consumed without rehydration, possessing a moisture content between 10% and 50%, and a water activity range of 0.65 to 0.90. Owing to these characteristics, they can often be preserved at room temperature. This classification underscores the importance of water activity in determining the shelf life and safety of food products, as it influences microbial growth, enzymatic activity, and chemical reactions within the food. Products with intermediate water activity strike a balance, being sufficiently dry to inhibit the growth of most pathogenic bacteria, yet moist enough to retain a palatable texture without the need for rehydration prior to consumption. This makes them particularly suitable for long-term storage at ambient conditions, offering a practical advantage in terms of both food safety and convenience.

Among meat products, dry-cured products are recognized for their unique sensory characteristics (Arnau et al., 2007). They are produced and consumed in different regions of the world and represent a significant market with demanding consumers looking for high-quality and safe products (Pizzolato Montanha et al., 2018). However, cured products have lower consumption rates compared to other processed meat products due to their higher production costs (Toldra, 2014).

Feiner (2006) presents a variety of dry-cured meats from around the world, including Parma ham, pancetta, and Parma coppa from Italy; Black Forest ham from Germany; Serrano ham from Spain; Biltong from South Africa; Pastirma from Turkey; Bunder fleisch from Switzerland; beef jerky from the United States; and Rou gan and shafu from China.

In Brazil, three meat products are particularly noted for their intermediate water activity: jerked beef, salami, and coppa. Each of these products undergoes distinct preparation processes that confer unique characteristics upon them. Jerked beef, distinctively, necessitates a desalination process prior to consumption, contrasting with coppa and salami, which are ready to eat following their respective drying and curing processes. This variation underscores the diversity in production techniques employed across these meat products and emphasizes the significance of each method in shaping their sensory properties and ensuring their preservation (Brasil, 2020).

Jerked beef is defined by Brazilian legislation (Brasil, 2020) as a dehydrated beef product, seasoned with salt and subjected to a drying process, having a maximum water activity of 0.78. In contrast, coppa, as described by the identity and quality standards for Brazilian meat products (Brasil, 2000), is made from specific cuts of pork, such as the neck or shoulder, which, after being seasoned, undergo a process of maturation and drying, and may also be smoked, resulting in a maximum water activity of 0.90. Salami is characterized by Brazilian legislation (Brasil, 2000) as an industrialized meat product, made from pork or a mixture of pork and beef, added with pork fat and other ingredients, and encased in natural or artificial casings. This product undergoes curing, fermentation, maturation, and, optionally, smoking and desiccation, presenting a maximum water activity of 0.92. The fermentation process distinguishes salami, endowing it with unique flavor characteristics and contributing to its preservation.

Another alteration that occurs in meat during this process is the change in color. The color of meat and meat products, an important aspect of consumer acceptability, is primarily dependent on the chemical state of the myoglobin pigment (red-purple) and the heme group protein. This pigment contributes approximately 80 to 90% of the total in fresh meat. Myoglobin is not the sole pigment, nor the most significant from a biological perspective, but it is the only one present in sufficient quantities to impart a red color to the meat (Sabadini et al., 2001).

Cured meats must have a strong and stable red curing color. To achieve a stable red curing color in meat products, sodium nitrite $NaNO_2$ dissociates into Na^+ and NO_2^-, where nitrite, the water-soluble, highly toxic salt of nitrous acid (HNO_2), plays a crucial role. If nitrate is used, it must first be reduced to nitrite, which then forms the curing color with myoglobin, the color of the meat (Feiner, 2016).

Sodium nitrite is a salt commonly utilized in meat curing processes in the production of ham, bacon, and sausages. Its primary function lies in preserving meat products by inhibiting the germination of *Clostridium botulinum* spores and impeding the growth of *Listeria monocytogenes*, among other microorganisms (Bellucci et al., 2021). Additionally, sodium nitrite possesses antioxidant properties that play a role in reducing product rancidity. It is well-recognized for its contribution to the development of the characteristic pinkish-red color and flavor attributes of cured meat products (Talon & Leroy, 2014).

Ascorbic acid and erythorbic acid are considered curing additives. They are not necessary but are useful in producing a higher quality cured product. Ascorbic acid and erythorbic acid and their salts are used to accelerate the development of cured meat color, act as reducing agents to accelerate the breakdown of nitrite to nitric oxide and maintain myoglobin in a reduced form for reaction with nitric oxide. They also act as stabilizers of the cured meat color and as antioxidants (Lonergan et al., 2019).

3. Sodium reduction strategy

NaCl is essential for a healthy diet and is necessary for the proper functioning of our body; however, excessive intake can be harmful. It is important to note that reducing salt intake can have a positive impact on blood pressure. Nevertheless, reducing salt intake can be challenging due to its significant contribution to the taste and processing of food.(Kilcast & den Ridder, 2007).

In many developed countries, reducing salt consumption can be achieved through a gradual and continuous reduction in the amount of salt added to food by the food industry. In other regions, where much of the salt consumed comes from salt added during preparation or from sauces, a public health campaign is essential to encourage consumers to reduce their use of salt (He & MacGregor, 2010). United Kingdom and United States guidelines recommend a salt intake of less than 6 g/day for adults (He & MacGregor, 2010), while the WHO has set a global target of a maximum intake of 5g/d (WHO, 2012).

Addressing the shift towards healthier dietary preferences and government-led initiatives for sodium reduction in foods has led to innovative strategies in meat processing. These include substituting NaCl with alternative salts like KCl, $MgCl_2$, and $CaCl_2$, with potassium chloride (KCl) being the most extensively researched due to its similar properties to NaCl, despite its potential to impart a bitter taste at certain concentrations (Desmond, 2006; Fulladosa et al., 2009; Nachtigall et al., 2019; Ripollés et al., 2011; Vidal et al., 2021). Notably, research by Purriños et al., (2012) has shown that the sensory attributes such as appearance, odor, flavor, and texture are not significantly compromised by the reduction of NaCl content, suggesting a viable pathway to healthier meat products without sacrificing taste or quality.

Salty and Saltiness-Enhancing Peptides represent another potential salt substitute utilized in the meat industry. Salty peptides are small molecule peptides that possess inherent saltiness, whereas saltiness-enhancing peptides exhibit activities that enhance saltiness (Chen et al., 2023).

Despite these sensory challenges, it is possible to reduce salt intake while still maintaining an adequate perception of salt and preserving other sensory properties. Salt reduction strategies must be tailored to each recipe, as the impact of salt reduction can vary depending on the food.(Kilcast & den Ridder, 2007).

Li et al. (2024) delved into the utilization of ultrasonic technology across various stages of meat processing, ranging from pre-treatment processes such as defrosting and cleaning, to curing and post-processing activities like freezing and packaging. They also examined the fundamental principles of ultrasonic technology, including cavitation effects, as well as mechanical and thermal effects, which are instrumental in enhancing meat quality. These enhancements encompass improvements in tenderness, water-holding capacity, and flavor profile, in addition to reducing the time required for the curing process. Ultrasonic technology, renowned for its non-destructive applications in the food industry, presents a promising avenue to address the challenges associated with sodium reduction. By employing high-frequency sound waves, this technology expedites the penetration of curing liquids into the meat, thereby augmenting water retention, tenderness, and the flavor of cured meat products.

Various strategies have been employed to reduce sodium content in meat products. These strategies include the direct reduction of the amount of NaCl used in the formulation, partial substitution of NaCl with other salts such as potassium chloride, calcium chloride, and magnesium chloride, the utilization of flavor enhancers and/or masking agents (examples include potassium chloride (KCl), yeast extracts, lactates, and monosodium glutamate), and the modification of the physical form of NaCl to enable quicker dissolution. This alteration enhances the perception of saltiness as it dissolves more rapidly, thereby intensifying the salty flavor as see Table 1.

Studies show that microbiological safety is maintained in meat products even with salt reduction (Vidal et al., 2019) Replacing 50% of NaCl with KCl had no negative effect on the properties and microbiology of low-fat Bologna sausages (dos Santos Alves et al., 2017) . On the other hand, microbiological activity should always be the focus of changes, as De Jesús et al. (2014) show that dry-cured ham may have an altered texture and foul odor due to proteolytic activity of microorganisms such as *Clostridium, Staphylococcus* and fungi such as *Cladosporium.*

Li et al. (2023) found that the sensory quality of beef jerky was reduced only by direct NaCl reduction, while all other treatments maintained or improved it. Therefore, it can be confidently concluded that partial replacement of NaCl in products is a viable method to reduce sodium content without compromising the sensory quality of beef jerky.

It is well-documented that KCl can cause a bitter, metallic, and astringent taste in the product when used as a replacement for more than 50% of NaCl (Pedro et al., 2021).

During the maturation period of dry cured meat, Toldrá (1998) reports intense lipolysis in the processing of dry-cured ham. A large percentage of the free fatty acids generated result from the hydrolysis of phospholipids, indicating an important role of phospholipases, this process gives rise to volatile compounds that contribute to the sensory characteristics of matured products. Muscle lipases are activated under saline conditions and low water activity.

NaCl also influences the activity of certain proteolytic enzymes, such as cathepsins and some proteases. Proteolysis reactions play a crucial biochemical role during the processing of meat products, particularly in the maturation process. The main products of proteolysis are small peptides and free amino acids, which influence flavor and texture (Aristoy & Toldrá, 1995; Mora et al., 2013; Toldra´, 1998). Fulladosa et al. (2021) demonstrated that a higher content of subcutaneous fat in ham delayed the dehydration process and facilitated proteolysis, in addition to weight loss.

Flores (2018) said that in dry-cured meat products a specific compound producing cured odor has not been identified. Due to the long ripening times that favors the generation of precursors and the low water activity that favors lipid oxidation and Maillard reactions, many sulfur and nitrogen compounds have been identified as aroma impact compounds. But Petričević et al. (2018). make the correlation with the aroma of dry-cured products is primarily attributed to the development of volatile compounds resulting from proteolysis and lipolysis occurring during the maturation phase of processing. These volatile compounds encompass aldehydes, alcohols, ketones, carboxylic acids, hydrocarbons, and others. Several biochemical alterations (lipolysis, proteolysis, oxidation reactions, Strecker degradation, and Maillard reactions) take place during the manufacturing and maturation of dry-cured products, thereby contributing to the flavor development

The employment of curing salts, such as sodium and potassium nitrate and nitrite, plays a pivotal role in hindering the proliferation of pathogenic bacteria, including Clostridium botulinum, and in maintaining the sensory attributes, such as color and flavor, of meat products. Recent studies have been investigating the possibility of substituting or supplementing sodium nitrite with antioxidants, whether synthetic, like ascorbic acid and BHA (butylated hydroxyanisole)/BHT (butylated hydroxytoluene), or derived from natural sources such as plants, fruits, and seeds, in addition to utilizing bacteriocins and specific bacterial strains. These antioxidants, particularly phenolic compounds, have been recognized for their effectiveness in preventing lipid oxidation and safeguarding against pigment degradation and microbial growth. Moreover, the encapsulation technique for sodium nitrate and nitrite, employing agents like maltodextrin and Tween 80, has been identified as a promising strategy to preserve the desired characteristics in dry-cured pork sausages during storage, thereby ensuring their quality, sensory acceptance, and stability.

4. Future prospects and challenges

In most developed countries, about 80% of salt is hidden in food, added by the food industry, and it will take a joint effort between academia and industry to achieve meaningful outcomes. (He & MacGregor, 2010).

In dry-cured products, an additional challenge beyond reducing the NaCl content is determining the end of the maturation process for these products. (Fulladosa et al., 2021) demonstrate that non-invasive technologies such as X-ray and magnetic resonance imaging have not yet been introduced to the market. The integration of these technologies "on-line" could significantly enhance the classification of raw hams, given that texture is affected by a multitude of factors beyond just fat and salt concentrations. The adoption of such technologies could enable the establishment of lower salt thresholds, as they would provide a more precise point of assessment, thus elevating both the safety and quality of the product.

Furthermore, several researchers (Andrés et al., 2004; Benedini et al., 2012) have identified a correlation between the fat content, the amount of drying, and the duration of the drying process. Given that salt exhibits greater solubility in lean meat compared to fatty tissues attributable to fat containing only a minimal water content (approximately 12-15%, in contrast to muscle tissue's 75% water content) the introduction of salt to cuts of meat that are either exceptionally fatty or possess a thicker subcutaneous fat layer will result in the salt predominantly dissolving in the lean portions of the meat cut (Feiner, 2006).

This nuanced understanding of how salt interacts differently with lean and fatty tissues underscores the complexity of achieving optimal curing conditions. It highlights the necessity for precise control over the curing process to maintain the balance between enhancing flavor and texture while also ensuring food safety. The potential application of non-invasive, real-time technologies represents a significant advancement in the field, offering the possibility to more accurately monitor and adjust the curing process. This, in turn, could lead to the production of cured meats that are not only safer and of higher quality but also more consistent in their sensory attributes (Fulladosa et al., 2021).

The rising consumer preference for natural and organic foods has significantly fueled the growth of the clean label product market. This market emphasizes the minimization of synthetic additives while prioritizing natural ingredients, a trend particularly noticeable in the meat product sector. This shift presents a challenge for producers: finding natural alternatives to traditional curing agents like nitrates and nitrites, which are essential for preserving the sensory qualities and safety of meat products. In this scenario, plant extracts offer a promising solution. For example, the Japanese radish (*Raphanus sativus L.*) is highlighted for its high concentration of natural nitrates and antioxidants, positioning it as an effective, natural option for meat curing that aligns with the clean label ethos (Guimarães et al., 2021).

However, the move towards clean labeling and natural ingredients comes with its own set of challenges, particularly in relation to salt substitutes. Despite the health-driven trend towards reducing the intake of salt, nitrites, nitrates, and fats, the integration of salt substitutes into food products is currently viewed with skepticism. Consumers are increasingly demanding simpler ingredient lists on food packaging, seeking to minimize their consumption of chemical compounds. Furthermore, the introduction of salt substitutes into the production process can lead to increased manufacturing costs (Hu et al., 2020). This highlights a complex balance that must be struck between meeting consumer demands for healthier, cleaner-labeled products and managing production feasibility and costs.

Addressing these challenges requires a nuanced understanding of how changes in meat product composition can impact flavor and aroma, especially when traditional ingredients are replaced or reduced. Reformulation strategies must consider the intricate interactions between the meat matrix composition and processing methods, as these factors play a crucial role in the generation of aroma and the release of flavor. The pursuit of natural strategies, focusing on the use of aroma precursors and leveraging biotechnological processes, becomes crucial in the development of high-quality aromatic meat products that align with current health trends and consumer preferences for natural ingredients (Flores, 2018).

Also moulds should be further explored in the production of dry-cured products as they play a significant role in their manufacture. The growth of moulds on the surface of meat is often beneficial, as they contribute to the development of flavours and aromas characteristic of dried meats, due to their fat and protein breaking activities (Sonjak et al., 2011).

The encapsulation of sodium nitrate and nitrite has been identified as an innovative and effective strategy for improving the quality and stability of cured meat products, such as dry-cured pork sausages. This technique facilitates a controlled release of curing salts, ensuring that high concentrations of sodium nitrite are maintained throughout extended storage periods. This is essential for preserving the sensory attributes of the meat, such as color and flavor, and for preventing the growth of pathogenic bacteria. The deployment of encapsulating agents like maltodextrin and Tween 80 has been demonstrated to be a practical and efficient method, safeguarding not only the quality and sensory appeal of the products but also enhancing their oxidative stability. The adoption of this encapsulation method marks a significant leap forward in food processing technologies, presenting a strategic approach to prolonging the shelf life and ensuring the safety of cured meat products (Cence et al., 2023).

Expanding the horizon of food reformulation, Onyeaka et al., (2022) introduce nanotechnology as a groundbreaking technique, particularly in the reduction of sodium, sugar, and fat in foods. Nanotechnology, which encompasses the development and application of structures within the size range of 1 to 100 nm, holds transformative potential for the food industry. It offers avenues for enhancing the color, texture, and flavor of food products, alongside improving the bioavailability of nutrients. Furthermore, the application of antimicrobial nanoparticles has emerged as a promising strategy for mitigating food spoilage, thereby extending product shelf life. These advancements underscore the capacity of nanotechnology to significantly elevate food quality and safety, showcasing its role as a pivotal tool in the ongoing efforts to reformulate and enhance food products for better health outcomes and consumer satisfaction.

Beck et al. (2021) highlight a novel strategy, initially applied in the baking industry (Noort et al., 2010) and currently being explored in meat products, including hamburgers (Gaudette et al., 2019) and fresh sausages. This strategy, known as sensory contrast technology, leverages the heterogeneous distribution of ingredients within a product. By doing so, it enables the reduction of certain ingredients, such as salt, in meat products without diminishing the perceived intensity of saltiness and without the need for sodium substitutes or flavor enhancers. Consequently, this technology offers a method to decrease specific ingredients while preserving the sensory quality of the food, marking a significant departure from traditional approaches that might compromise taste or texture.

In parallel, the application of data-mining techniques and machine learning presents a promising avenue for understanding the chemical dynamics within food matrices, although this method shows the most promise in simpler food systems. The process of food reformulation, taking into account the influence of the food matrix, requires a deep dive into the physicochemical interactions within foods. This approach aims to optimize nutrient delivery and reduce undesirable components, contrasting with traditional food reformulation strategies. Historically, these strategies have adopted a reductionist perspective, focusing on decreasing components in food associated with health risks. This shift towards a more holistic understanding of the food matrix for reformulation purposes underscores the complexity of balancing nutrient content without sacrificing sensory attributes, thereby aligning with contemporary health and wellness trends (Onyeaka et al., 2023).

The Pulsed Electric Field technology, as explored by Guo et al. (2024), offers a promising solution particularly in the aspect of sodium reduction in meat products. This technology operates by altering the permeability of cell membranes, which in turn facilitates the deeper penetration of curing agents. This mechanism allows for a more uniform and efficient distribution of these agents within the muscle tissue, thereby not only enhancing the maturation and curing processes but also potentially reducing the sodium content without compromising the quality and safety of the meat products.

Moreover, the application of ultrasonic technology in meat curing processes is gaining attention due to its effectiveness in altering the structure of muscle fibers and enhancing the permeability of biofilms, as highlighted by Li et al. (2024b). These modifications are essential for optimizing the curing process, significantly reducing the required time for curing, and ensuring a notable improvement in the final product's quality. The achievement of uniform curing without compromising the overall quality of the product underscores the primary advantages of ultrasonic technology. Additionally, its capability to improve key quality aspects such as tenderness, water-holding capacity, NaCl permeability, and flavor of meat products, through the acceleration of NaCl penetration and the promotion of critical chemical reactions like the Maillard reaction, lipid oxidation, and protein degradation, has been documented (Bai et al., 2023).

The efficiency of ultrasonic technology in enhancing the physicochemical and sensory properties of meat products, coupled with its potential to reduce the time and costs associated with the curing process, positions it as a standout choice. The innovative approach of integrating ultrasonic technology with other curing methods creates a synergistic effect, offering novel solutions to the industry's challenges This synergy underscores the evolving nature of food processing technologies, which continue to adapt and innovate in response to the demands for sustainability, quality, and consumer health (Li et al., 2024b).

5. Final Considerations

Current strategies are focused on identifying substitutes and optimizing curing techniques to preserve the sensory, physicochemical properties, and safety of the products without compromising taste or increasing the risk of foodborne pathogens. The modification of product structure and the use of chloride salts without sodium, flavor enhancers, basic amino acids, and innovative curing technologies to evenly distribute NaCl and enhance the perception of saltiness, thereby reducing the required amount, are examples of applied practices.

Future research should concentrate on the structural optimization of NaCl, a detailed analysis of sodium release from the food matrix, and the careful integration of methods to reduce sodium content. The goal is to develop dry-cured meat products with reduced sodium content without negatively affecting food safety or consumer acceptance. In this context, the synergy between innovative ingredients, enhanced processes, and the application of new technologies stands as the fundamental tripod for future advancement. This multidisciplinary approach promises not only to meet demands for safety and palatability but also to align food production with the needs of a healthy lifestyle, marking the pathways to be followed by the food industry.

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Table 1 - Strategies for Sodium Reduction

Salt reduction method	Strategy employed	Sample	Effect	Sodium reduction	Reference
Salt replace					
	Partial replacement of NaCl by KCl mixed with $CaCl_2$	Salami	It was well accepted by the panelists and with a small addition of substitutes had a sensory acceptability close to that of the commercial product.	64%	Almeida et al. (2016)
	Partial replacement with KCl, $CaCl_2$ and $MgCl_2$	Pastırma	Replacing 50 per cent of the NaCl with KCl did not significantly affect the product, but the use of $CaCl_2$ and $MgCl_2$ resulted in lower sensory scores.	50%	Yalınkılıç et al. (2023)
	Partial replacement with KCl and $CaCl_2$	Jerked beef	$CaCl_2$ negatively impacted sensory properties, water activity reduction, and color; KCl exhibited technological and sensory characteristics similar to the control.	50%	Vidal et al. (2019)
	Partial replacement NaCl with KCl and using lysine and liquid smoke as flavor enhancers	Low-fat Bologna-type sausages	The substitution only affected the sensorial quality, reducing the salty taste and giving a bitter and metallic taste. The addition of lysine and/or liquid smoke was able to reverse the sensory defects caused by partial NaCl replacement.	50%	dos Santos Alves et al. (2017)
	50% molar substitution of NaCl by mixtures of KCl and K-lactate	Small calibre fermented sausages	A 50% reduction in NaCl content can be achieved through molar substitution with KCl (50%) or a combination of KCl/K-lactate (40:10), without compromising the overall acceptability of the product.	50%	Guàrdia et al. (2008)
	Partial replacement of NaCl with KCl, CaC_{l2} and $MgCl_2$	Dry-cured ham	treatment 55% NaCl, 25% KCl, 15% CaCl2, and 5% MgCl2 led to slightly higher lipolysis, and a lower inhibition of acid lipase activity. Hams treated with 100% NaCl showed delayed oxidation compared to the other treatments tested, though by the end of the process, the oxidation levels were the same for all three treatments.	< 45%	Ripollés et al. (2011)

	Partial replacement of NaCl by Soda-Lo® salt microspheres	Deli type sausages, Cooked ham and turkey breast	Substituting NaCl with Soda-Lo® salt microspheres at varying levels (25%, 30%, 50% by weight) did not affect the sensory qualities or microbial properties.	30.07% 21.93% 10%	Raybaudi-Massilia et al. (2019)
	Reduction of NaCl	Fermented dry sausages	The use of 2.0% added NaCl in fermented sausages showed the best quality and flavor, without compromising their physicochemical and sensory properties.	20%	Hu et al. (2020)
	Partial replacement of NaCl by KCl and reductions in the re-salting time	Coppa	A sensory evaluation revealed that reducing the re-salting time was effective according to the Ideal Profile Method, indicating that treatments T1 (2 days initial salting + 2 days re-salting, 35% NaCl reduction) and T2 (2/3/35%), successfully met consumer expectations.	20%	Domenico et al. (2021)
Saltiness enhancer					
	Replacement of 50% and 75% of NaCl with KCl with combination of monosodium glutamate, lysine, taurine, disodium inosinate, and disodium guanylate	Fermented cooked sausages	the incorporation of monosodium glutamate, disodium inosinate, disodium guanylate, lysine and taurine maintained adequate physicochemical and sensory attributes when replacing 50% NaCl with KCl and effectively mitigated the adverse effects of replacing 75% NaCl with KCl.	68%	dos Santos et al. (2014)
	Partial replacement with KCl, L-histidine and L-lysine	Dry-cured loin	The inclusion of l-histidine and l-lysine in the formulation not only postponed lipid oxidation and slightly intensified lipolysis, resulting in a higher concentration of free fatty acids and increased phospholipase activity by the end of the ripening process, but also improved the physicochemical characteristics.	53,79%	Zhang et al. (2015)
	Partial replacement with KCl and $CaCl_2$, along with the use of lysine and yeast extract.	Salted meat	lysine and yeast extract in minimizing the negative sensory effects caused by the addition of $CaCl_2$, without altering the physicochemical quality parameters and safety of the products. Additionally, it reveals that a blend of NaCl + KCl exhibited sensory characteristics similar to the control treatment.	50%	Vidal et al. (2020)

	Partial replacement with KCl, L-lysine, and L-histidine	Dry-cured beef	The addition of L-histidine and L-lysine made little contribution to bitterness and increased the intensity of the salty taste, showing a synergistic effect on the salinity of NaCl. (39.7% NaCl, 51.3% KCl and a mixture of 7% L-lysine and 2% L-histidine)	<50%	Liu et al. (2020)
	Partial Replacement with Pansalt® or *Laminaria Ochroleuca* seaweed powder	Dry-cured foal "cecina"	Pansalt® (T1) and Kombu seaweed powder (T2) effectively reduced sodium levels, with minimal impact on physicochemical and sensory properties, except for a lower saltiness in T2.	39% 48%	Cittadini et al. (2023)
	Psrtial replacement with KCl and with the addition of monosodium glutamate (MG)	Dry-cured rabbit leg	Reducing NaCl by 50% resulted in a less salty perception. However, the addition of KCl negatively affected texture, while incorporating MG improved texture attributes and overall consumer perception.	46.2%	Pedro et al. (2021)
	Reduced-salt with glasswort hydrates (carboxymethyl cellulose, carrageenan, isolated soy protein, sodium caseinate)	Frankfurters	Improved cooking loss, water holding capacity (WHC), hardness, emulsion stability, and viscosity. Treatments containing glasswort hydrate with carboxymethyl cellulose, with carrageenan, and with isolated soy protein also improved the sensory attributes related to texture (tenderness and juiciness) of the sausages.	< 33,3%	Lim et al. (2015)
	Partial replacement with potassium lactate and lysine	Dry-cured ham	A formulation with low sodium content, comprising 8% potassium lactate, 12% lysine, and 70% NaCl, could serve as an effective alternative for decreasing the NaCl content while enhancing the quality of dry-cured ham throughout the ripening process.	< 30%	Liu et al. (2023)
	Partial replacement with KCl, maltodextrin, L-Lys, L-Ala, citric acid and Ca-lactate	Harbin dry sausage	Treatments did not destroy the physical characteristics. Formulation of low-sodium substitutes appears to be a reliable strategy to mask the defects caused by replacing NaCl with KCl, resulting in a better quality	30%	Chen et al. (2019)
	Partial replacement with KCl, calcium ascorbate and calcium glutamate	Fermented Sausages	Changed the composition of the bacterial community and accelerated the drying and ripening processes, without causing significant differences	< 25%	Zhang et al. (2021)

			in texture and color characteristics compared to traditional products. Despite a slight reduction in resilience and brightness.		
Ultrasound					
	Ultrasound-assisted dry curing (UDC) and tumbling dry-curing	Bacon	60 minutes at 300 W has been shown to enhance the texture and sensory properties of reduced-sodium bacon	75%	Pan et al. (2020)
	Ultrasound-assisted curing	Jerked beef	Improved yield, tenderness, and water activity. In general, the combination of partially replacing NaCl with KCl and ultrasonic treatment showed significant improvements in the quality of the dry-cured meat,	50%	Li et al. (2023)
	Ultrasound and potassium chloride combination	Low sodium restructured cooked ham	Ultrasound and KCl separately enhance low-sodium restructured cooked ham's quality, with KCl being slightly more effective. Combining both does not provide extra benefits.	50%	Barretto et al. (2020)
	Ultrasound combined with sodium bicarbonate-assisted curing	Chicken breast	Ultrasound-assisted curing exhibited a synergistic effect in enhancing curing rate, tenderization, and water-binding capacity.	-	Xiong et al. (2020)

Capítulo 2

IMPACT OF NaCl PARTIAL REPLACEMENT BY KCl AND $CaCl_2$ ON PHYSICOCHEMICAL PROPERTIES AND SENSORIAL PREFERENCE OF DRY-CURED *COPPA.*

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Impact of NaCl Partial Replacement by KCl and $CaCl_2$ on Physicochemical Properties and Sensorial Preference of Dry-Cured *Coppa.*

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ABSTRACT: As a result of the health trend, there is a growing concern about the adverse effects of excessive NaCl consumption. The high-sodium diet has been associated with an increase in the incidence of cardiovascular diseases. However, this reformulation represents a big challenge due to the contribution of sodium in the physical-chemical and sensory properties of meat products with intermediate water activity. This study aimed to evaluate the effect of the addition of KCl and $CaCl_2$ in dry-cured *Coppa* with reduction of NaCl in the physicochemical properties and sensorial acceptance. Five treatments were performed: CON (2.6% of NaCl); 25K (1.95% NaCl and 0.65% KCl), 25KCa (1.95% NaCl, 0.39% KCl and 0.26% $CaCl_2$), 50K (1.30% NaCl and 1.30% KCl) and 50KCa (1.30% NaCl, 0.65% KCl and 0.65% $CaCl_2$). The mixture of KCl and $CaCl_2$ (50KCa) increased the hardness and chewiness. The reduction of up to 50% NaCl (50K) with the addition of KCl improved the color parameters and increased the intensity of redness. The overall acceptability was not affected by the partial substitution of NaCl up to 40%. Thus, the mixture of KCl and $CaCl_2$ as a partial substitution of NaCl could represent an alternative to the development a dry-cured *Coppa* with a healthier appeal.

Keywords: Salt reduction, Overall acceptability, Dry-cured meat.

1. INTRODUCTION

Researchers and the food industry are pursuing ingredient replacements for NaCl (sodium chloride) in meat products, due to the potential risk of excessive ingestion by consumers (Inguglia et al., 2017; de Sousa et al., 2020; Vargas-Ramella et al., 2021). Furthermore, there is a change in consumer habits towards desiring healthier meat products that may contain reduced amounts of worrisome ingredients such as NaCl. This change of habit is due to the association between high NaCl consumption and the potential development of diseases like hypertension, cardiovascular diseases, and other chronic non-communicable conditions, in addition to weight gain (Ruusunen & Puolanne, 2005; Schivazappa & Virgili, 2020).

The dry-cured *Coppa* is made from raw muscle material taken from the pork shoulder, which undergoes a dry curing process using ingredients like NaCl and seasonings. This process takes place over a period, during which the product is placed in a maturation chamber to decrease moisture and water activity (Zanardi et al., 2000). Cured meat products are well received by consumers (Pérez-Burillo et al., 2020). However, cured meat products like dry-cured *Coppa* may contain high NaCl content in their formulation. The search for the reformulation of cured meat products, such as dry-cured *Coppa* is a challenge that researchers have been investigating to make them healthier (Lorenzo et al., 2015a); Santos et al., 2021; Vargas-Ramella et al., 2021).

NaCl is a widely used ingredient in the processing of meat products, duo to its attributes that are directly related to important sensory characteristics such as flavor, aroma, texture, and color. Additionally, it acts as an antimicrobial agent, reduces water activity, and extends shelf life (Cubero-Castillo et al., 2019; Rios-Mera et al., 2021). Furthermore, NaCl promotes various functionalities in meat products, such as enhancing the solubility of myofibrillar proteins, reducing water activity, controlling the development of discoloration in cured products, and affecting lipid oxidation, as NaCl is a pro-oxidant agent (Mitchell, 2019), in addition to influencing numerous biochemical reactions, including proteolysis and lipolysis (Jia et al., 2024). The partial reduction of NaCl in meat products has been investigated through the addition of alternative chlorides, such as calcium chloride ($CaCl_2$), potassium chloride (KCl), and magnesium chloride ($MgCl_2$) (Aliño et al., 2010; Barretto et al., 2020; Horita et al., 2011; Barretto et al., 2018; Vidal et al., 2019; de Sousa et al., 2020; Pinton et al., 2021; Santos et al., 2021)

Ionic strength is one of the factors considered when attempting to replace NaCl. Taylor et al. (2018) and Zheng et al. (2019) have examined the chemical characteristics of NaCl. Among the characteristics that resemble NaCl, one lies in the valence of monovalent cations (KCl) and divalent cations ($CaCl_2$). Due to this ionic similarity, KCl enhances the solubility of myofibrillar proteins, thereby improving the texture profile. Additionally, it has a microbial inhibitory effect (Bidlas & Lambert, 2008). However, the partial replacement of NaCl with KCl has characteristics that, when incorporated in high amounts, can result in undesirable sensory attributes such as a bitter taste, metallic taste, and/or astringent taste, in addition to a loss of salinity (Zheng et al., 2019). Therefore, this study aimed to evaluate the effects of the partial replacement of NaCl by KCl and $CaCl_2$ on technological properties and sensory acceptance of dry-cured *Coppa*.

2. MATERIALS AND METHODS

2.1. Material

The raw material meat used was the muscle of the pork shoulder refrigerated obtained in the region of Catanduva, São Paulo, Brazil. The ingredients utilized in dry-cured *Coppa* were obtained and provided for Jamones Salamanca Industry of Canned Company ® (Catanduva, São Paulo, Brazil), and potassium chloride (KCl), calcium chloride ($CaCl_2$) utilized were provided for New Max Industry Company (Americana, São Paulo, Brazil).

2.2. Manufacture of dry-cured Coppa with reduction of NaCl

A completely randomized design (CRD) was conducted with five distinct treatments, where each treatment was repeated three times. In each repetition, six experimental units were used for each treatment. Each experimental unit consisted of a pork shoulder pieces (66.7% moisture, 22.9% protein, and 7.9% lipid) with an average weight of 1.5 kg, were randomly divided into five groups and subjected to a process of salting, curing, and maturation. The different treatments were Control - CON (2.6% NaCl), 25K (1.95% NaCl and 0.65% KCl), 25KCa (1.95% NaCl, 0.39%KCl and 0.26% $CaCl_2$), 50K (1.30% NaCl and 1.30% KCl) and 50KCa (1.30% NaCl, 0.65% KCl and 0.65% $CaCl_2$). The dry-cured *Coppa* treatments were produced according to described by Romeo et. al. (2014) which consisted of the application of salts (NaCl, KCl, $CaCl_2$) in the proportion of 2.6% concerning the weight of raw material. The other ingredients added were 2.5% seasonings (paprika, garlic, and oregano), 0.35% mixture of sodium nitrate and sodium nitrate, 0.3% monosodium glutamate, 0.25% mixture of sodium erythorbate and ascorbic acid. Those ingredients were rubbed on the surface of the pork shoulder pieces, then the pieces were massaged, and the samples were relocated in containers separate according to different formulations and maintained for seven days in the chamber at 3 ± 1 °C and 90% RH (relative humidity) for the cured process. Seven days later, the pieces were stuffed in collagen cases (diameter of 85 mm) and ripened for 42 days in the chamber of maturation with temperature and humidity controlled (15°C/ 75% RH).

2.3. Technological characterization

The analysis of the determination of moisture, protein, and ash was realized in accordance with AOAC (2012). The weight loss was calculated by the difference between the initial weight and the final weight of the product. The values of water activity (aw) were measured using an Aqualab water activity meter (decagon Devices Inc., Pullman, USA). The pH value was measured with a penetration probe in an mPA-210 digital pH meter (Tecnopon, São Paulo, Brazil).

2.4. Instrumental color

For the instrumental color analysis, each treatment was sliced into pieces of 2 mm thickness the measured the instrumental color parameters of L*, a*, and b. The instrumental color analysis was performed in a ColorFlex 45/0 spectrophotometer (Hunterlab, Virginia, USA), observation angle of 10°, with D65 illuminant and linked to Universal software version 4.10. The samples were placed with an internal diameter of 75 mm, and they were analyzed ten times in different positions for each piece. The specification system used was the CIELAB color space expressing the three values: L* for lightness, a* for redness, and b* for yellowness. These analyses were performed after the ripening time of dry-cured *Coppa* with reduced NaCl (42 days).

2.5. Texture profile analysis

The texture profile analysis (TPA) was realized using a TA-XT/Plus/50 texture analyzer (Stable Micro Systems Goldaming, UK), at room temperature (25°C), equipped with a cylindrical probe, 36 mm in diameter. The parameters of hardness (N), cohesiveness (N), springiness, and chewiness (N) were determined as described by Bourne (1978). The samples of each treatment were cut into 2 cm cubes and were compressed to 50% of height (1 cm) in two consecutive cycles, at a constant speed test of 1 mm s^{-1} (n = 15). These analyses were performed after the ripening time (42 days).

2.6. Microbiological analysis

The microbiological analysis was performed after 42 days of ripening of dry-cured *Coppa* reduced NaCl in all treatments according to the microbiological standards established by Brazilian legislation (BRASIL, 2019). To analyze the coagulase-positive *Staphylococci*, thermo-tolerant *Coliforms,* and sulfite-reducing *Clostridium* and the presence *Salmonella sp.* in 25 g. The results obtained were expressed in log CFU^{-1} of the sample.

2.7. Determination of Calcium, Potassium and Sodium content

The determination of calcium, potassium, and sodium content was realized for dry digestion, according to Barretto et al. (2018).

2.8. Sensorial preference

With restricted movement due to the coronavirus pandemic, the Department of Food Technology and Engineering (UNESP, São José do Rio Preto, SP, Brazil) implemented changes. Panelists were selected remotely, and samples were dispatched to their respective homes, accompanied by detailed instructions for conducting the analysis. Once the microbiological analysis ensured the safety of the samples, the evaluation was carried out.

The ranking sensory test was used to evaluate preference, the panelists were asked to rank the samples, assigning a score of 1 to the most preferred and 5 to the least preferred. The different formulations were assessed for overall acceptance. The samples were arranged in a randomized order and individually coded with three-digit numbers for all participants, along with instructions on the sequence to follow. To determine if the differences between the samples were significant, a total score for each sample was calculated, and the data were analyzed using the Friedman test.

The samples for sensory evaluation were dispatched to each taster in vacuum-sealed packages and were appropriately identified (Fig. 1). The analysis involved 39 untrained consumers individuals well-acquainted with meat product consumption. This group consisted of members from the academic community, including graduate students and employees of the Institute of Biosciences, Letters, and Exact Sciences at the State University of São Paulo

(UNESP/IBILCE), as well as external participants. This project had previously been approved by the Research Ethics Committee of UNESP-IBILCE (39388020.5.0000.5466).

2.9. Statistical analysis

The results of proximate composition, weight loss, pH values, instrumental color, water activity, determination of calcium, potassium, and sodium content values, hardness, cohesiveness, springiness, and chewiness were analyzed through a variance analysis (ANOVA), with a complete randomized block design, using the generalized linear model (GLM) and the difference in means were measured by the Tukey HSD test at a level of significance of 95% *(p > 0.05)*. Data from three repeating were analyzed, where lots were considered as random terms, and the times were considered as fixed terms. The values were presented as mean values and standard error of the mean (SEM).

For sensory analysis, the treatments were defined as fixed effects and the tasters as random effects. To verify if there was a significant difference between the samples, the Friedman Test was applied, according to the one described by Bis-Souza et al. (2020).

3. RESULTS

3.1. Technological characterization

A significant difference *(p < 0.05)* was observed for fat and ash (Table 1), with no difference for protein and moisture *(p < 0.05)* among treatments. The CON presented higher values (25.13) for fat content, and the treatment 25KCa obtained lower values (20.18), already the treatments 25K and 50KCa had no differences between CON and 50K**.**

For ash content, the treatment 50KCa (5.80) showed a lower value in comparison with the treatment 25K (6.29), which received a higher value for those ash parameters. These values agree with another study with a similar dry-cured meat product (Cittadini et al., 2020). Therefore, moisture and protein content showed no significant differences *(p < 0.05)* between the treatments. These results go against statements in the literature that with a reduction in the sodium content added to the meat product, the moisture content could increase, which would be more favorable to the proliferation of spoilage and pathogenic microorganisms, reducing the microbiological safety of the product (Jia et al., 2024). In this case, the moisture and protein content of all treatments agree with the Brazilian Legislation established: Limits maximum for moisture (40%) and protein (20% minimum) content (Brazil, 2000).

The results for the water activity parameter are presented in Table 1, where is possible to observe which treatment 50KCa presented the higher value of 0.9185 to treatment 25K which obtained a lower value of 0.8984, although this difference among treatments presented, these values are within of found by other authors which investigated the reducing NaCl in meat products with the addition of KCl, $CaCl_2$ (Vidal et al., 2019). Those results are similar be those found by (up to 0.93) (Lorenzo et al., 2015 b), which evaluated the influence of the salting time in formulations of dry-cured foal "cecina". The highest value (50KCa) and the lowest value (25K) did not show a significant difference between the control treatment, which reinforces the previous statement that this reduction in sodium (up to 50%) in this type of product would not significantly affect microbiological safety.

For the pH values (Table 1) there were obtained significative differences ($p < 0.05$) among the treatments, in which 25K obtained the higher pH value and 50KCa the lower pH value. This difference could be due to the presence of $CaCl_2$ at 25% concentration.

About the results of weight loss (Table 1) there was no significant ($p < 0.05$) difference between the means of different treatments. The weight loss corresponding to the evaporated water during the ripening occurs in the production process of dry-cured *Coppa*, furthermore, weight loss may change during the ripening process, which can be attributed to the position that the pieces may be allocated in a ripening chamber (Santos et al., 2021).

3.2. Instrumental color, Texture profile analysis and mineral content

Changes in the color parameters during the ripening and drying of meat products are due to various factors such as dehydration, acidification, and oxidation processes (Libera et al., 2015). A significant difference ($p < 0.05$) was observed in the color parameters after the 42 days of ripening time. The instrumental color parameters (Table 2) were influenced by the difference in the addition of NaCl in the treatments. 25KCa showed the highest value of L^* compared to the samples with no addition of calcium chloride. In contrast, 25KCa showed the lowest ($p < 0.05$) value for a^*. Those results may suggest the addition of calcium chloride as a NaCl substitute can make pork dry-cured *Coppa* treatments whiter, decreasing the intensity of the red color (characteristic in cured meat products).

The results for the hardness parameter (Table 2) presented differences significative ($p < 0.05$) between the different treatments, which varied from 46.135 (CON) to 53.635 (50KCa), the treatments CON and 25K presented lower values of treatments 25KCa, 50K and 50KCa which obtained the higher means for hardness parameter. For the cohesiveness parameter, the treatment presented significant differences ($p < 0.05$), where the treatment 50KCa obtained a higher mean (0.054) differing from treatment CON which resulted in a lower mean (0.031). The means for the chewiness parameter showed different significative ($p < 0.05$), which varied between 13.984 (50KCa) to 9.940 (CON). Already, the springiness parameter did not have a significant ($p < 0.05$) difference for the different treatments of dry-cured *Coppa* with partial replacement NaCl by $CaCl_2$ and KCl.

Similar results were presented by Lorenzo et al. (2015a) for texture profile parameters such as hardness (up to 20.33), cohesiveness (0.30), and chewiness (5.05).

Vidal et al. (2019) reported that the state of the protein and the decrease of moisture can collaborate with the increase of texture profile parameters. Furthermore, the structure chemical of chlorides utilized may increase the hardness of meat products, which can be seen in values of treatment 50KCa, which contains 25% $CaCl_2$ and 25% KCl. (Zheng et al., 2019) write about the ionic strength of $CaCl_2$ which is three times greater the NaCl which may collaborate for the increase of the values for texture profile parameters.

There was a reduction significative ($p < 0.05$) of sodium content for different treatments of dry-cured *Coppa* with reducing NaCl (Table 2) among the treatments, where the sodium content was lower for treatments 50K (1203.3 mg/100g of sample) and 50KCa (1190.9 mg/100g of sample), those results differ of treatment CON (1992.9 mg/100g of sample), which obtained the higher value for the sodium content. The calcium content was higher for treatment 50KCa (320.21 mg/100g) followed by treatment 25KCa (116.18 mg/100g). For the potassium content, the value of treatment 50K (1338.60 mg/100g) was higher, followed by values of treatments 50KCa (1096.97 mg/100g 5), 25K (991.15 mg/100g), 25KCa (638.15 mg/100g) and treatment CON (118.23 mg/100g).It was possible to reduce around 40% of the sodium content in a dry-cured *Coppa* with the strategy of adding KCl and using a mixture of $CaCl_2$ and KCl (50K and 50KCa). It is worth noting that the product in question is a cured meat product to which a high amount of sodium chlorate is traditionally added and the 40% reduction without significant technological changes represents a great achievement for meat product technology.

Similar results were reported by Leonardo Betiol et al. (2020), with a reduction of 41% in the sodium content in dry-cured ham and Chinese Bacon with partial substitution by KCl and calcium ascorbate (Zhang et al., 2020).

3.3. Microbiological analyses

All the microbiological results obtained in this study were within established limits according to Brazilian legislation (Brazil, 2019).

3.4. Sensorial preference

Understanding consumer perceptions is an important strategy that can lead to the reformulation of meat products with reduced/substituted NaCl, according to Pateiro et al. (2021) modifying the NaCl content and adding substitutes will change the same physicochemical characteristics of the meat product and consequently may affect consumer acceptance. However, the literature, in general, has shown that changes in salt content with up to 50% NaCl substitution did not directly affect the overall acceptability of meat products.

Similar results were obtained in treatments of dry-cured *Coppa* (Table 3) for the overall acceptability. Those results showed that the panelists found no difference between the formulations despite the NaCl being replaced. This agrees with the results found by (Yim et al., 2018; Chen et al., 2019) who manufactured Harbin dry sausage and Salami with salt replacement.

4. DISCUSSION

The fat and ash content may vary according to the raw material utilized and the anatomic difference between each carcass, according to Ferreira de Campos et al. (2022) and Gamero-Negrón et al. (2015) which causes the heterogeneity of the dry-cured shoulders as products. However, despite the significant differences found between the treatments, all results agree with the technical regulation of identity and quality of dry-cured Coppa, which establishes a maximum of 35% of fat (Brazil, 2000).

Barretto et al. (2018) reported that the differences in ash content can probably be a result of the varying content of salts used in the different formulations.

Domenico et al. (2021) reported that the heterogeneity of the pieces, with different fat content and different spatial arrangement in the piece, affected the maturation process and it was not possible to state the relationship between the salt content and the percentage of moisture of the product.

Zheng et al. (2019) describe the relationship between ionic strength and the interaction with myofibrillar protein of different mixture chlorides, where the KCl and NaCl have similar ionic strength, however, the $CaCl_2$ have higher ionic strength and weight atomic which NaCl and KCl, the which may explain the relation of exchange water with ambient.

Vargas-Ramella et al. (2021) reported similar differences in the pH values using salt mixture I (30% NaCl 70% KCl) and salt mixture II (30% NaCl-50% KCl-15% $CaCl_2$-5 % $MgCl_2$) when compared to the control treatments. The results of this study of weight loss corroborate with the findings (Armenteros et al., 2012), which investigated the evolution of nitrite and nitrate during the processing of dry-cured ham with partial reduction of NaCl by $CaCl_2$, $MgCl_2$, and KCl, where for weight loss the different treatments varied between 32% to 34% after the production process.

The b* values were like those reported by other authors in the production of cured *Coppa* (Ferreira de Campos et al., 2022) and other authors observed that during ripening, all samples of dry-cured *coppa* became darker due to the increase in a* value (Libera et al., 2015). Horita et al. (2011) corroborate the idea that the differences found in the staining parameters are related to the differences in the physicochemical characteristics of the treatments. The study of a substitution in NaCl by a mixture of $CaCl_2$ and $MgCl_2$ in dry-cured foal “Cecina” obtained the result of an increase in lightness and a decrease in redness compared to the control treatment (Cittadini et al., 2020).

Vidal et al. (2019) reported that the ionic strength and water retention capacity may promote the increased texture parameters, and the reduction the NaCl can affect various characteristics in meat dry-cured products and intervene directly in the texture of meat products as the dry-cured Coppa.

So, the incorporation of $CaCl_2$ and KCl in dry-cured Coppa affected parameters such as color, hardness, cohesiveness, chewiness, pH, and water activity. At the levels employed in this study to reduce salt (40% reduction), no adverse effects were observed on sensory characteristics. Replacing 50% of NaCl added with KCl and $CaCl_2$ provided sodium reduction and did not affect sensory preference, showing that this strategy can be used in meat products with intermediate activity to obtain a dry-cured Coppa with healthier appeal.

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Figure. 1 Vacuum-packed dry-cured *Coppa* samples received by the panelists.

Source: Ignácio, E. O (2024).

Table 1 - Proximate composition, water activity (Aw), pH values, and weight loss of dry-cured *Coppa*.

	Treatments					*SEM*	*P value*
	CON	25K	25KCa	50K	50KCa		
Moisture	32.77	32.34	32.69	31,24	33.15	0.322	n.s.
Fat	25.13^{a}	23.35^{ab}	20.18^{c}	22.67^{b}	23.11^{ab}	0.548	0.004
Protein	36.07	34.72	38.17	36.99	36.61	0.639	n.s.
Ash	5.97^{ab}	6.29^{a}	6.00^{ab}	6.12^{ab}	5.80^{b}	0.060	0.038
Aw	0.9092^{ab}	0.8984^{b}	0.9001^{ab}	0.9065^{ab}	0.9185^{a}	0.003	0.036
pH values	6.02^{ab}	6.13^{a}	5.94^{b}	6.00^{b}	5.72^{c}	0.038	< 0.01
Weight loss	38.04	36.52	39.72	37.87	38.12	0.597	n.s.

$^{a, b, c,}$ According to Tukey test, treatments on the same line with different letters show significant differences between them. ($p < 0.05$); SEM: standard error of the mean. CON = 100% NaCl; 25K = 75% NaCl e 25% KCl; 25KCa = 75% NaCl, 15%KCl e 10% $CaCl_2$; 50K = 50% NaCl e 50% KCl e 50KCa = 50% NaCl, 25% KCl e 25% $CaCl_2$.

Table 2 – Texture profile analysis, instrumental color and calcium, potassium, and sodium content of dry-cured *Coppa*.

	Treatments						
Parameters	CON	25K	25KCa	50K	50KCa	**SEM**	***P < value***
Hardness	46.13^{b}	46.83^{b}	50.54^{ab}	51.95^{ab}	53.63^{a}	0.91	0.02
Cohesiveness	0.03^{b}	0.04^{ab}	0.04^{ab}	0.05^{ab}	0.05^{a}	0.00	0.04
Springiness	7.01	5.98	7.39	7.32	6.43	0.22	n.s.
Chewiness	9.94^{b}	9.29^{b}	11.88^{ab}	13.12^{a}	13.98^{a}	0.43	< 0.01
L*	43.35^{b}	46.54^{ab}	50.89^{a}	42.31^{b}	47.32^{ab}	0.81	< 0.01
a*	16.14^{a}	15.52^{a}	10.57^{b}	17.27^{a}	14.79^{a}	0.51	< 0.01
b*	12.76^{b}	13.70^{ab}	10.53^{c}	14.53^{a}	13.28^{b}	0.27	< 0.01
Calcium content	6.26^{c}	5.72^{c}	116.18^{b}	4.62^{c}	320.21^{a}	32.75	< 0.01
Potassium content	118.23^{e}	991.15^{c}	638.15^{d}	1338.60^{a}	1096.97^{b}	113.35	< 0.01
Sodium content	1992.88^{a}	1593.36^{b}	1606.50^{b}	1203.36^{c}	1190.92^{c}	79.76	< 0.01

[a, b, c,] According to Tukey test, treatments on the same line with different letters show significant difference between them. ($p < 0.05$); SEM: standard error of the mean; n.s. = Not significant; CON = 100% NaCl; 25K = 75% NaCl e 25% KCl; 25KCa = 75% NaCl, 15%KCl e 10% $CaCl_2$; 50K = 50% NaCl e 50% KCl e 50KCa = 50% NaCl, 25% KCl e 25% $CaCl_2$.

Table 3 –Sensorial preference of dry-cured Coppa.

	CON	25K	25KCa	50K	50KCa
Overall acceptability	104	109	114	117	131

[a, b, c,] According to Tukey test, treatments on the same line with different letters show significant difference between them. ($p < 0.05$); SEM: standard error of the mean; n.s. = Not significant; CON = 100% NaCl; 25K = 75% NaCl e 25% KCl; 25KCa = 75% NaCl, 15%KCl e 10% $CaCl_2$; 50K = 50% NaCl e 50% KCl e 50KCa = 50% NaCl, 25% KCl e 25% $CaCl_2$

Capítulo 3

INFLUENCE OF TEMPERATURE AND CHEMICAL COMPOSITION ON THE WATER SORPTION ISOTHERMS OF COMMERCIAL *COPPAS*

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Influence of temperature and chemical composition on the water sorption isotherms of commercial *Coppas*

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Abstract

Pork meat stands out due to its many applications in the development of various processed meat products. *Coppa* is one of these products, obtained from the cut of the neck region, which undergoes the salting and maturing process. Temperature, equilibrium moisture and water activity are parameters that must be considered during production and storage, as they are correlated with chemical and microbiological stability. The aim of this research was to present the proximate chemical composition and sorption isotherms of eight commercial *coppas* at temperatures of 5, 10, 20, 30 and 40°C. The chemical composition was determined using the methods described in the AOAC, while the sorption isotherms were obtained using the gravimetric method. In general, the samples showed different proximal chemical composition. The isotherms were classified as type II, sigmoidal behavior. The GAB, Peleg, Oswin, Henderson and Halsey models were fitted to the experimental data, with the GAB model showing the best fit ($R^2_{adj} \geq 0.99$, $\chi^2 \leq 3.84.10^{-4}$ and RMSE ≤ 0.02). The moisture content of the monolayer (X_m) showed a downward trend with increasing temperature. The sample with the highest sodium content (C3) had a higher equilibrium moisture content (X_{eq}) than the sample with the lowest sodium content (C1), for constant water activity (a_w).

Keywords: equilibrium moisture; water activity; meat products; mathematical modeling.

1. Introduction

The Brazilian Association of Pig Breeders (ABCS) reported a 6.73% growth in pork production between the first half of 2021 and 2022. There are several reasons for this: it is a source of nutrients such as proteins, lipids, fatty acids, mineral substances and vitamins (Yi et al., 2023), the affordable value of the meat, and the possibility of making various derivatives such as hamburger (Bellucci et al., 2022), fresh sausage (Araya-Morice et al., 2023), salami (Bis-Souza et al., 2020; Cence et al., 2023), *coppa* (Di Domenico et al., 2020; Rocchetti et al., 2023) and Parma ham (Zanardi et al., 2000).

Coppa is pork product that has undergone a salting and maturing process, resulting in characteristics similar to those of salami (Rutigliano et al., 2023). It originated in northern Italy in the Emilia Romagna region. However, its production extends to other regions of Italy, resulting in different recipes. Despite the regional variations, it is produced with some similar stages (Taddei et al., 2020). The production process consists of obtaining pork called shoulder, a region of the neck with a cylindrical shape and marbled fat, considered a noble cut. The trimmings are removed from the piece of meat, a homogeneous mixture of salt, curing agents and flavorings is prepared, spread on the surface of the meat and left to rest in a refrigerated environment for salting. It is then stuffed into natural or synthetic casings, the ends tied and hung in a drying chamber to reduce moisture. Finally, the maturation stage can last for weeks at a temperature of 10 - 20°C and relative moisture of 70 to 90% until it has the desired characteristics (Rutigliano et al., 2023; Taddei et al., 2020).

The paragraph above emphasizes the significance of temperature and relative moisture parameters in *coppa* production. Adjusting these parameters can lead to optimized production. Adjusting these parameters can lead to optimized production and is related to biochemical changes, microbial growth, and lipid oxidation (Rocchetti et al., 2023). Water activity is a very important property in meat products as it is directly related to chemical, biochemical and microbial stability. Sorption isotherm graphs illustrate the relationship between water activity and equilibrium moisture at a constant temperature and pressure (Bauer et al., 2022). Using these two sets of experimental data, water activity and equilibrium moisture, mathematical modeling can be performed to simulate stability conditions during storage and drying. This allows for a better understanding of the physicochemical changes and shelf life of dehydrated products (Rosa et al., 2021).

The literature presents sorption isotherms for various meat products, including ham (Barretto et al., 2018; Leonardo Betiol et al., 2020), salami (Bauer et al., 2022) and sausage (Polatoğlu et al., 2011), No isotherms were found for *coppa*. This study aims to assess the impact of temperature and chemical composition on the water sorption isotherms of eight commercial *coppa*s. Furthermore, the mathematical modeling of five models, GAB, Peleg, Oswin, Henderson and Halsey.

2. Material and methods

2.1 Sample preparation

Eight brands from three different batches were purchased at a local market in São José do Rio Preto, São Paulo, Brazil. Each sample was labeled with a code (C1 to C8) to guarantee the confidentiality of the brands. The samples were vacuum-packed in polyethylene bags (0.15 mm thick) lined with aluminum foil and stored at -12°C. They were thawed at 5°C for the experiments and analyses.

2.2 Chemical composition

The chemical composition of the eight commercial *coppa* samples was determined according to the AOAC methods. Official Methods of Analysis (AOAC, 2007). The components determined and the methodologies used were protein (micro-Kjeldahl), fat (Soxhlet), ash (incineration), moisture (gravimetric), carbohydrate (by difference), and sodium (Möhr).

All the analyses were carried out in triplicate to obtain the mean and standard deviation. The ANOVA statistical test was then performed, followed by the Tukey test with a 95% confidence level to check for significant differences between the samples.

2.3 Determination of sorption isotherms

The sorption isotherms of the *coppa* were determined in triplicate using the gravimetric method according to the methodology of Leonardo Betiol et al. (2020) and Barretto et al. (2018) applied to dry-cured ham and cooked ham, respectively.

The methodology involves exposing the product to an environment with a known a_w (Table 1), monitoring the weight of the sample until it reaches equilibrium moisture, and then determining it. Three 1g (±0.1 mg) samples of *coppa* were placed in containers. Then, the containers were positioned on a support inside a desiccator so that the samples did not come into contact with the saturated salt solution and were exposed to relative moisture. The weight of the sample was monitored using an analytical balance (AUY220, Shimadzu, Kyoto, Japan) with a precision of 0.1 mg until it reached a constant weight, changing by no more than 0.1% based on the dry weight. The equilibrium moisture was then determined using the gravimetric method (AOAC, 2007).

To provide different a_w, fourteen types of saturated saline solution were prepared according to the solubility data from (Martins et al., 2023). In addition, to ensure the solution was saturated, the presence of decanted salt at the bottom of the desiccator was checked. This procedure was carried out at temperatures of 5, 10, 20, 30, and 40°C in a BOD chamber (MA415, Marconi, Piracicaba, Brazil).

After obtaining the equilibrium moisture, the isotherm graphs (a_w x X_{eq}) were plotted using OriginPro 8.0 software (OriginLab Corporation, Northampton, USA).

2.4 Mathematical Modeling of Sorption Isotherms

After obtaining the equilibrium moisture content and plotting the sorption isotherms, the following models were fitted to the experimental data: GAB (Eq. 1) (Lewicki, 2020), Peleg (Eq. 2) (Peleg, 1993), Oswin (Eq.3) (Oswin, 1946) , Henderson (Eq.4) (Henderson, 1952) and Halsey (Eq.5) (Halsey, 1948). OriginPro 8.0 software (OriginLab Corporation, Northampton, USA) was used to perform the nonlinear regressions. Mathematical modeling was evaluated using adjusted coefficient of determination (R_{adj}^2), reduced chi-square (χ^2) and root mean square error (RMSE).

$$x_{eq} = \frac{X_m \cdot C \cdot k \cdot a_w}{(1 - k \cdot a_w) \cdot (1 + (c - 1) \cdot k \cdot a_w)} \tag{1}$$

$$x_{eq} = k_1 \cdot a_w^{n_1} + k_2 \cdot a_w^{n_2} \tag{2}$$

$$x_{eq} = M \cdot \left(\frac{a_w}{1 - a_w} \right)^N \quad (3)$$

$$x_{eq} = \left(-\frac{1}{H_1} \cdot \ln\left(1 - a_w\right) \right)^{\frac{1}{H_2}} \quad (4)$$

$$x_{eq} = \left(-h_1 \cdot \ln\left(a_w\right) \right)^{-\frac{1}{h_2}} \quad (5)$$

where x_{eq} is equilibrium moisture (b.s), a_w is water activity, M, N, k, k_1, k_2, n_1, n_2, H_1, H_2, h_1, h_2, X_m, C and k are the model parameters.

3 Results and discussion

3.1 Chemical composition

The chemical composition of eight commercial *coppas* was analyzed in triplicate (Table 2) and statistically tested. The samples had different compositions due to variations in processing conditions, formulations, and raw material characteristics.

The protein content ranged from 23.86 to 32.72 g/100g, with significant differences between some groups of samples. Samples C1, C2, and C3 did not show significant differences, as did groups C4, C7, and C8, and C5 and C6. The results were similar to those of other commercially processed meat products, such as salami (Meynier et al., 1999) and ham (Leonardo Betiol et al., 2020).

The lipid content ranged from 19.69 to 30.60 g/100g. Sample C4 showed a significant difference between all the samples tested. This difference is associated with the raw material used, pork, due to the different genetic characteristics of the pig breeds and the range of feeding systems (Jiménez-Colmenero et al., 2010). In addition, Jiménez-Colmenero et al. (2010) show that lipid content is one of the components that is directly linked to texture, flavor and appearance.

Moisture content ranged from 38.33 to 43.95 g/100g between the samples. Sample C2 showed a significant difference compared to all the other samples tested, and the same behavior was observed for sample C6. Di Domenico et al. (2020) presented moisture contents close to those of the present study, ranging from 32.56 to 43.32 % for different storage periods (0, 30, 60 and 90 days) of pork *coppa* with reduced sodium content. When making a dry meat product, controlling the moisture content is essential, as reducing moisture inhibits the growth of microorganisms, reduces chemical degradation and consequently extends shelf life (Aykın-Dinçer & Erbaş, 2018).

In general, moisture, protein and lipids showed significant differences between the samples. This behavior could be explained by the different processing conditions between manufacturers, such as the ripening period. Rocchetti et al. (2023) checked the influence of the ripening period (0, 60, 90, 180 and 240 days) on the chemical composition of *Coppa* Piacentina PDO. It was observed that a longer ripening time is associated with a tendency to reduce moisture and increase protein and lipid content. This phenomenon can be explained by the increase in dehydration over the course of the days, which consequently results in an increase in the dry matter content. This same behavior was shown by Seong et al. (2015) for dry-cured loin.

The sodium content varied greatly between the samples, from 1366 to 2958 mg/100 g. Sample C3 showed a significant difference compared to the other samples tested, representing the sample with the highest sodium content. The same behavior was observed for sample C1, but it represented the sample with the lowest sodium content. Upon analysis of the results, it can be seen that sample C3 had more than twice the sodium content compared to sample C1. Sodium chloride is a primary ingredient in salting preparations, providing stability against microbiological degradation and resulting in greater storage stability. In addition, Seong et al. (2014) demonstrate that reducing the sodium content can affect the texture of dry-cured ham, a product similar to *coppa.*

3.2 Sorption isotherms

Figure 1 shows the sorption isotherms of eight commercial *coppas* (C1 to C8), based on the fitted GAB model, with equilibrium moisture ranging from 0.20 to 0.97 (g of water.100 g of dry matter) and water activity from 0.06 to 0.98. Several behaviors can be described. The isotherms for milder temperatures are generally higher than those obtained at higher temperatures. For a constant equilibrium moisture, the water activity increased as the temperature rose. However, for a constant water activity, a rise in temperature leads to a reduction in equilibrium moisture. This pattern has been observed for various foods, such as pork liver (Sánchez-Torres et al., 2021), ham (Leonardo Betiol et al., 2020), pork (Comaposada et al., 2000) and beef (Ahmat et al., 2014) and salami (Bauer et al., 2022).

The second observation can be explained by the behavior of the water molecules. A higher temperature results in a greater degree of freedom and kinetic energy between the molecules, which reduces the forces of attraction between the molecules. This makes the molecules less stable and prone to separating from the water-food bonding sites (Al-Muhtaseb et al., 2002), consequently reducing the moisture content.

Brunauer et al. (1940) presented the classification of isotherms from Type I to Type V. According to the behavior of the data shown in Figure 1, it is possible to classify the isotherms as Type II, which has a sigmoid shape. This behavior is described for different products such as ora-pro-nobis leaves (Borges-Machado et al., 2024), pepper (Getahun et al., 2017), beef (Ahmat et al., 2014), sausage (Polatoğlu et al., 2011) and ham (Barretto et al., 2018).

The type II isotherm is composed of three distinct regions: the first is represented by the monolayer tightly bound to the food matrix, followed by the second region represented by the moisture of the multilayer transition moment, and finally, the third region, represented by the water available for chemical and microbiological reactions, which remains retained in the capillaries and crevices of the food (Rosa et al., 2021; Yan et al., 2012).

Figure 2 shows the sorption isotherms as a function of chemical composition and sodium content. Samples C1 and C3 were chosen due to the great difference in sodium content. It was observed that the sodium content influenced the behavior of the sorption isotherms. For a given water activity, sample C3, which has a higher sodium content, showed a slightly higher equilibrium moisture value than sample C1. This trend was observed mainly for $a_w \geq 0.55$. Leonardo Betiol et al. (2020) reported the same trend, but with a more significant difference in equilibrium moisture between the two samples compared. This behavior, in which a higher sodium content provides a higher equilibrium moisture content, is due to sodium chloride (NaCl) dissociating into Na^+ and Cl^- ions, providing greater interaction with water and reducing vapor pressure, which will consequently present a higher equilibrium moisture content.

3.3 Mathematical modeling

The GAB, Peleg, Henderson, Oswin and Halsey models were fitted to the experimental water activity and equilibrium moisture data. In general, the GAB, Peleg and Henderson models showed more satisfactory results, with higher R^2_{adj}, and lower $\chi 2$ and RMSE compared to the Oswin and Halsey models.

The GAB model was used to plot the water sorption isotherms of the eight commercial *coppas* due to the satisfactory results obtained in the fits, $R^2_{adj} \geq 0.99$, $\chi 2 \leq 3.84.10^{-4}$ and RMSE $\leq$ 0.02 and because it provides a physical explanation of the X_m parameter (moisture content of the monolayer). This parameter is associated with the stability and shelf-life of products during processing and storage (Yan et al., 2012). It is also a widely used model for determining the isotherms of processed meat and meat products (Ahmat et al., 2014; Aykın-Dinçer & Erbaş, 2018; Barretto et al., 2018; Leonardo Betiol et al., 2020; Polatoğlu et al., 2011; Sánchez-Torres et al., 2021)

Table 3 data indicates that X_m decreases as temperature increases. The studies by (Barretto et al., 2018; Leonardo Betiol et al., 2020), and (Polatoğlu et al., 2011) demonstrate a similar trend for meat products, specifically ham and sausage. Leonardo Betiol et al. (2020) attribute this trend to the physicochemical changes resulting from increased temperature, which in turn reduces the number of active sorption sites.

According to Blahovec (2004), isotherms can also be classified based on the values obtained for the C and K parameters of the GAB model. Type II isotherms should have $0<K\leqslant 1$ and $C>2$ and type III isotherms should have $0<K\leqslant 1$ and $0\leqslant C\leqslant 2$. Therefore, based on the values obtained in Table 3, it is possible to classify the isotherm as Type II according to (Brunauer et al., 1940).

4. Conclusion

It can be concluded that the eight commercial *coppas* have different chemical composition and sodium content. The sorption isotherms show type II behavior, according to the classification of Brunauer et al. (1940). The GAB model was chosen due to its satisfactory results ($R^2_{adj} \geq 0.99$, $\chi 2 \leq 3.84.10^{-4}$ and RMSE $\leq$ 0.02) and because it provides a physical explanation of the X_m parameter (equilibrium moisture of the monolayer). For all the samples, increasing the temperature led to a downward trend in equilibrium moisture. The sodium content of the samples had a slight influence on the behavior of the isotherms; for a given water activity and temperature, the sample with the highest sodium content had slightly higher equilibrium moisture values.

This finding underscores the utility of mathematical models in the food industry, providing insights to enhance the quality, stability, and economic profitability of products, as well as underpinning future research aimed at aligning products with consumer preferences.

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Table 1 - Water activity of saturated salt solutions at temperatures between 5 and 40°C.

Salts	5 ºC	10 ºC	20 ºC	30 ºC	40 ºC
LiBr	0.0743	0.0714	0.0661	0.0616	0.0580
LiCl	0.1126	0.1129	0.1131	0.1128	0.1121
LiI	0.2168	0.2061	0.1856	0.1657	0.1455
$MgCl_2$	0.3366	0.3347	0.3307	0.3244	0.3160
NaI	0.4242	0.4183	0.3965	0.3615	0.3288
K_2CO_3	0.4313	0.4314	0.4315	0.4317	-
$Mg(NO_3)_2$	0.5886	0.5736	0.5438	0.5140	0.4842
NaBr	0.6351	0.6215	0.5914	0.5603	0.5317
KI	0.7330	0.7211	0.6990	0.6789	0.6609
NaCl	0.7565	0.7567	0.7547	0.7509	0.7468
$(NH_4)_2SO_4$	0.8242	0.8206	0.8134	0.8063	0.7991
KCl	0.8767	0.8677	0.8511	0.8362	0.8232
KNO_3	0.9627	0.9596	0.9462	0.9231	0.8903
K_2SO_4	0.9848	0.9818	0.9759	0.9700	0.9641

Source: Martins et al. (2023) e Labuza (1963).

Table 2 - Mean values (± standard deviation) of the percentage composition of commercial *coppas.*

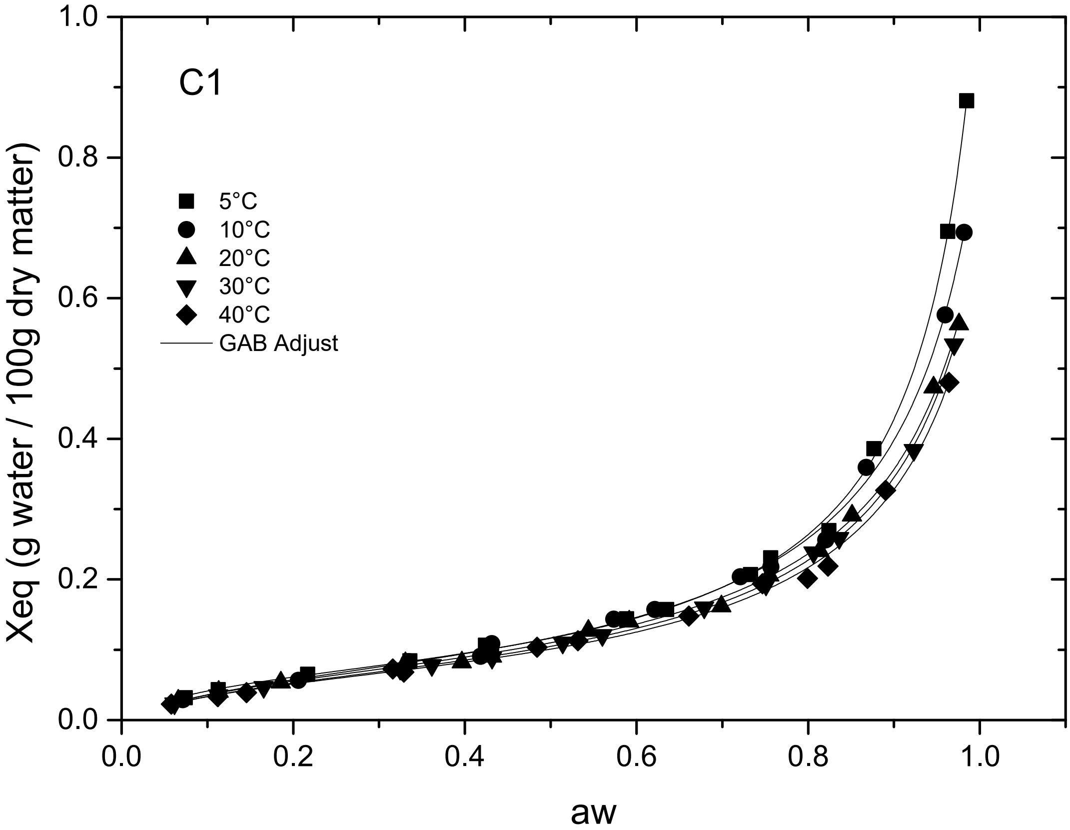
Chemical composition	Samples							
	C1	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**	**C8**
Protein (g/100 g)	32.72±0.39^{a}	32.71±0.15^{a}	31.44±0.52^{a}	29.97±0.32^{b}	23.86±0.89^{c}	24.77±0.42^{c}	29.76±0.24^{b}	29.32±0.62^{b}
Lipid (g/100 g)	22.01±0.49^{c}	22.65±0.10^{c}	19.69±0.44^{e}	24.22±0.19^{b}	30.36±0.27^{a}	30.60±0.47^{a}	20.64±0.47^{de}	21.78±0.80^{cd}
Ash (g/100 g)	2.43±0.04^{d}	2.50±0.05^{d}	4.76±0.08^{a}	2.76±0.04^{c}	2.49±0.01^{d}	2.43±0.00^{d}	2.64±0.07^{c}	3.04±0.00^{b}
Moisture (g/100 g)	41.58±0.14^{c}	39.65±0.96^{d}	42.88±0.17^{ab}	42.19±0.64^{bc}	41.47±0.20^{c}	38.33±0.03^{e}	43.95±0.18^{a}	42.39±0.34^{bc}
Carbohydrate (g/100 g)	1.26±0.56^{bc}	2.49±1.23^{abc}	1.23±1.07^{bc}	0.87±1.09^{c}	1.82±0.84^{abc}	3.86±0.57^{a}	3.00±0.82^{abc}	3.47±0.57^{ab}
Sodium (mg/100 g)	1366±105^{d}	1769±105^{c}	2958±67^{a}	2274±54^{b}	2230±10^{b}	1777±47^{c}	1831±17^{c}	2200±49^{b}

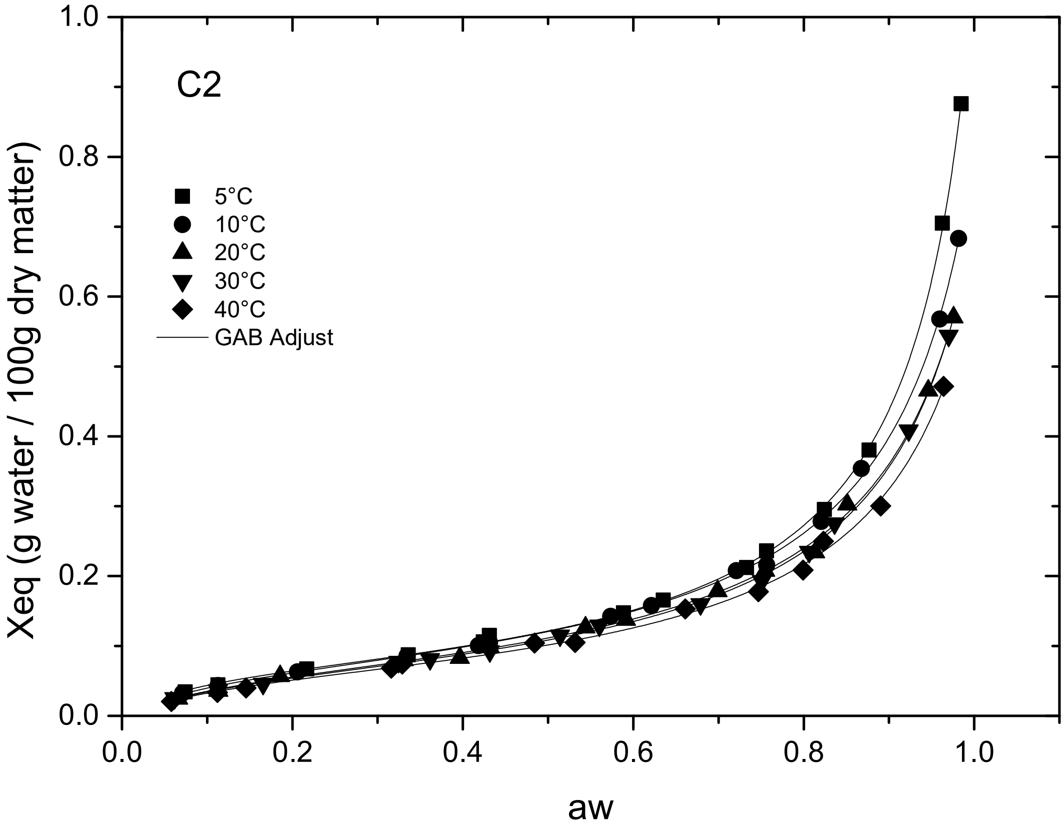
Means on the same line with different superscript letters are significantly different ($p<0.05$).

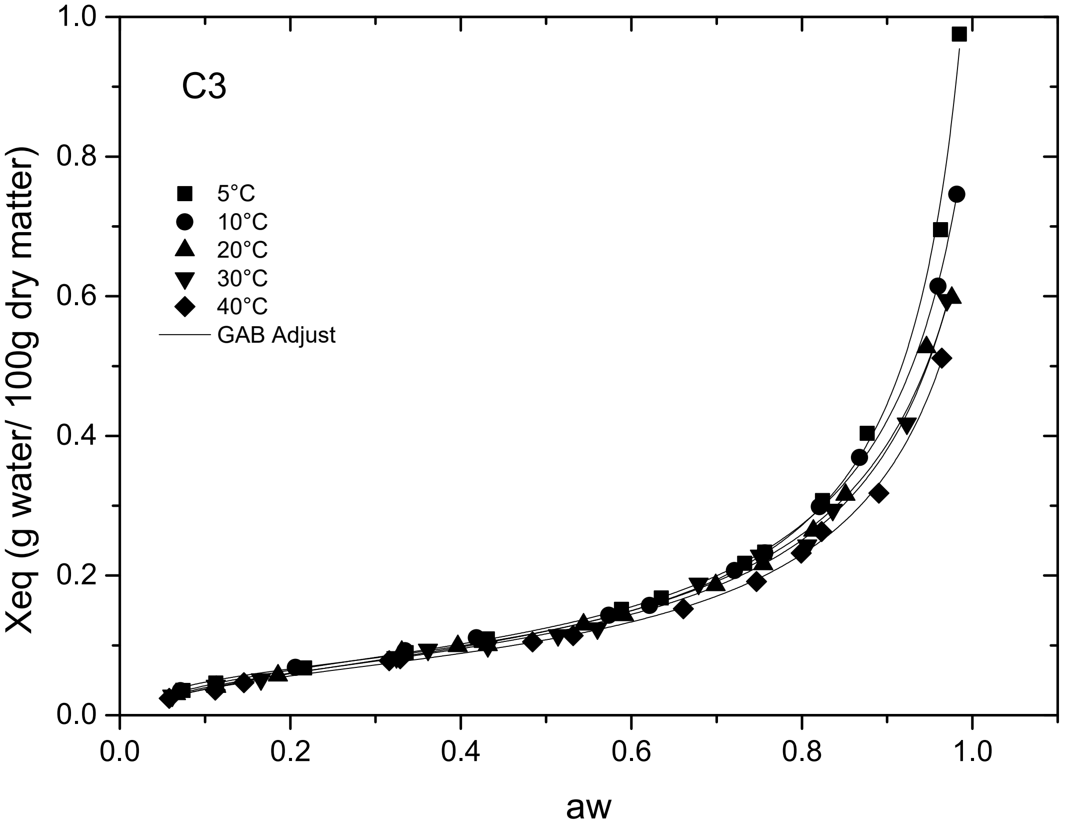
Table 3 - Mathematical parameters of the GAB model.

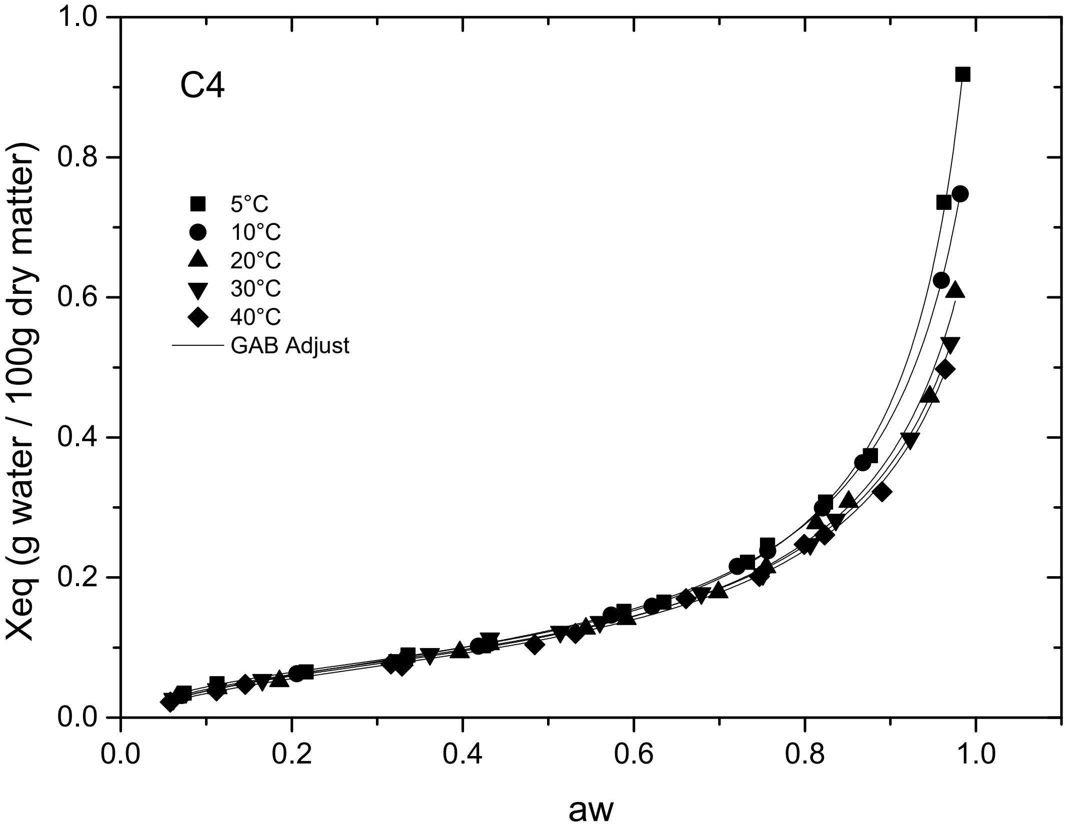
Samples	T (K)	X_m	*C*	*K*	R^2	X^2	MSE
C1	278.15	0.0729	7.1555	0.9323	0.9980	$1.26 \cdot 10^{-4}$	0.0112
	283.15	0.0683	10.1410	0.9170	0.9951	$1.99 \cdot 10^{-4}$	0.0141
	293.15	0.0677	9.0780	0.9035	0.9978	$5.88 \cdot 10^{-5}$	0.0077
	303.15	0.0652	8.7963	0.9064	0.9996	$9.42 \cdot 10^{-6}$	0.0031
	313.15	0.0623	9.5000	0.9051	0.9946	$9.32 \cdot 10^{-5}$	0.0097
C2	278.15	0.0742	10.0539	0.9320	0.9983	$1.07 \cdot 10^{-4}$	0.0104
	283.15	0.0707	11.2066	0.9122	0.9978	$8.41 \cdot 10^{-5}$	0.0092
	293.15	0.0700	8.4876	0.9010	0.9981	$5.05 \cdot 10^{-5}$	0.0071
	303.15	0.0678	8.5013	0.9050	0.9990	$2.26 \cdot 10^{-5}$	0.0048
	313.15	0.0636	8.7726	0.8990	0.9969	$5.20 \cdot 10^{-5}$	0.0072
C3	278.15	0.0761	6.9643	0.9345	0.9948	$3.84 \cdot 10^{-4}$	0.0196
	283.15	0.0755	10.2684	0.9165	0.9995	$2.47 \cdot 10^{-5}$	0.0050
	293.15	0.0712	8.5943	0.9008	0.9875	$3.84 \cdot 10^{-4}$	0.0196
	303.15	0.0680	11.6653	0.9111	0.9950	$1.30 \cdot 10^{-4}$	0.0114
	313.15	0.0660	10.4383	0.9044	0.9978	$4.15 \cdot 10^{-5}$	0.0065
C4	278.15	0.0774	6.5505	0.9307	0.9980	$1.37 \cdot 10^{-4}$	0.0117
	283.15	0.0733	8.3074	0.9156	0.9945	$2.61 \cdot 10^{-4}$	0.0161
	293.15	0.0795	5.6944	0.8898	0.9949	$1.46 \cdot 10^{-4}$	0.0121
	303.15	0.0726	10.5656	0.8918	0.9988	$2.50 \cdot 10^{-5}$	0.0050
	313.15	0.0711	7.8686	0.8879	0.9963	$7.00 \cdot 10^{-5}$	0.0084
C5	278.15	0.0749	10.1417	0.9345	0.9990	$7.01 \cdot 10^{-5}$	0.0084
	283.15	0.0726	10.8811	0.9161	0.9972	$1.24 \cdot 10^{-4}$	0.0112
	293.15	0.0721	11.2006	0.9007	0.9953	$1.28 \cdot 10^{-4}$	0.0113
	303.15	0.0709	7.0972	0.9042	0.9953	$1.15 \cdot 10^{-4}$	0.0107
	313.15	0.0699	7.9628	0.8947	0.9988	$2.34 \cdot 10^{-5}$	0.0048
C6	278.15	0.0745	8.5709	0.9307	0.9988	$7.56 \cdot 10^{-5}$	0.0087
	283.15	0.0717	9.9128	0.9091	0.9961	$1.50 \cdot 10^{-4}$	0.0123
	293.15	0.0698	7.7499	0.8989	0.9967	$8.92 \cdot 10^{-5}$	0.0094
	303.15	0.0689	9.0365	0.9034	0.9980	$4.41 \cdot 10^{-5}$	0.0066
	313.15	0.0680	7.5932	0.8917	0.9974	$4.48 \cdot 10^{-5}$	0.0067
C7	278.15	0.0744	10.3665	0.9154	0.9961	$1.69 \cdot 10^{-4}$	0.0130
	283.15	0.0720	10.5372	0.9090	0.9967	$1.25 \cdot 10^{-4}$	0.0112
	293.15	0.0717	9.6520	0.8936	0.9989	$2.69 \cdot 10^{-5}$	0.0052
	303.15	0.0715	8.7301	0.8996	0.9951	$1.08 \cdot 10^{-4}$	0.0104
	313.15	0.0685	7.6362	0.8801	0.9906	$1.54 \cdot 10^{-4}$	0.0124
C8	278.15	0.0756	8.1670	0.9352	0.9977	$1.61 \cdot 10^{-4}$	0.0127
	283.15	0.0743	9.5028	0.9139	0.9992	$3.74 \cdot 10^{-5}$	0.0061
	293.15	0.0738	7.6053	0.8938	0.9961	$1.02 \cdot 10^{-4}$	0.0101
	303.15	0.0712	7.8365	0.8970	0.9917	$1.98 \cdot 10^{-4}$	0.0141

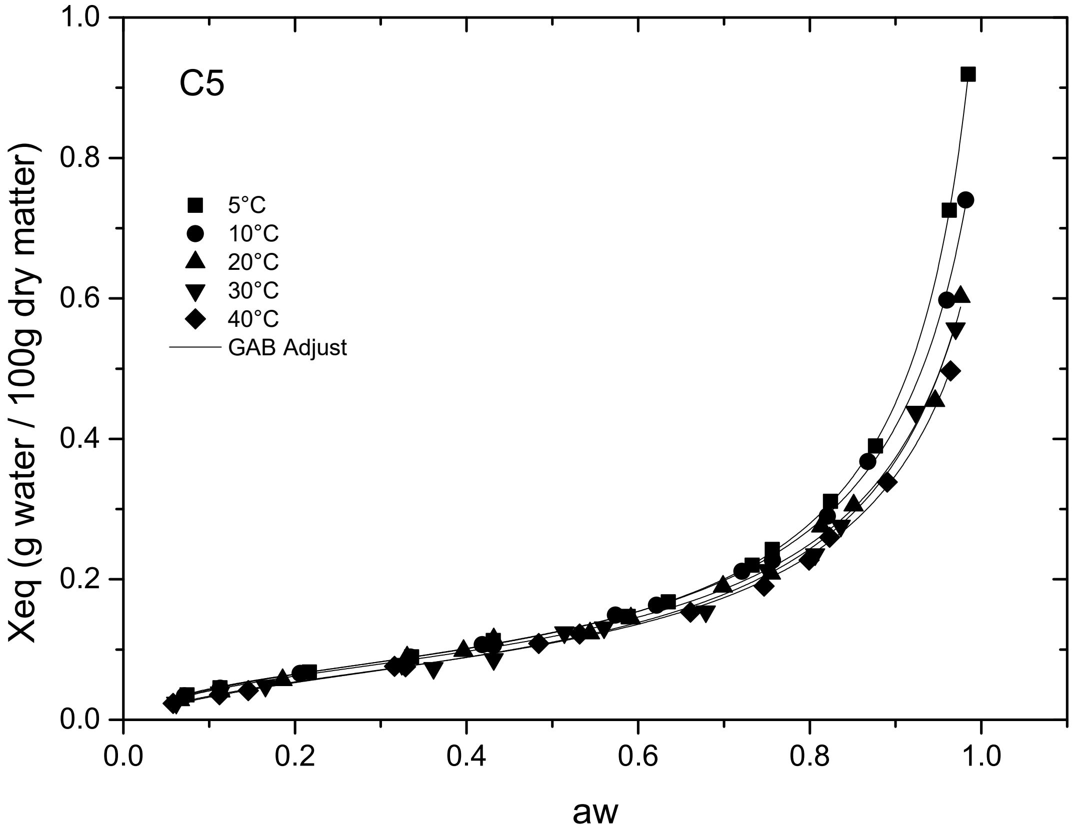
Figure 1- Influence of temperature on the sorption isotherms of eight commercial *coppas* (C1 to C8).



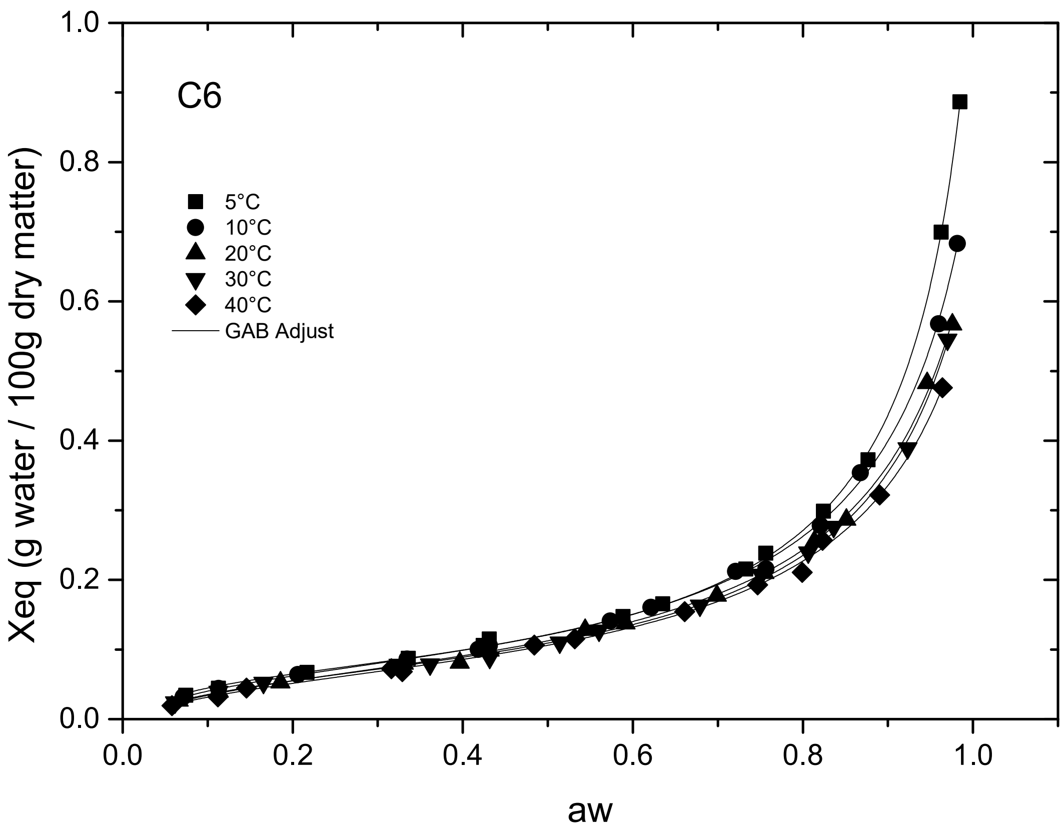



C3
5°C
10°C
20°C
30°C
40°C
GAB Adjust
Xeq (g water/ 100g dry matter)
aw
0.0
0.2
0.4
0.6
0.8
1.0

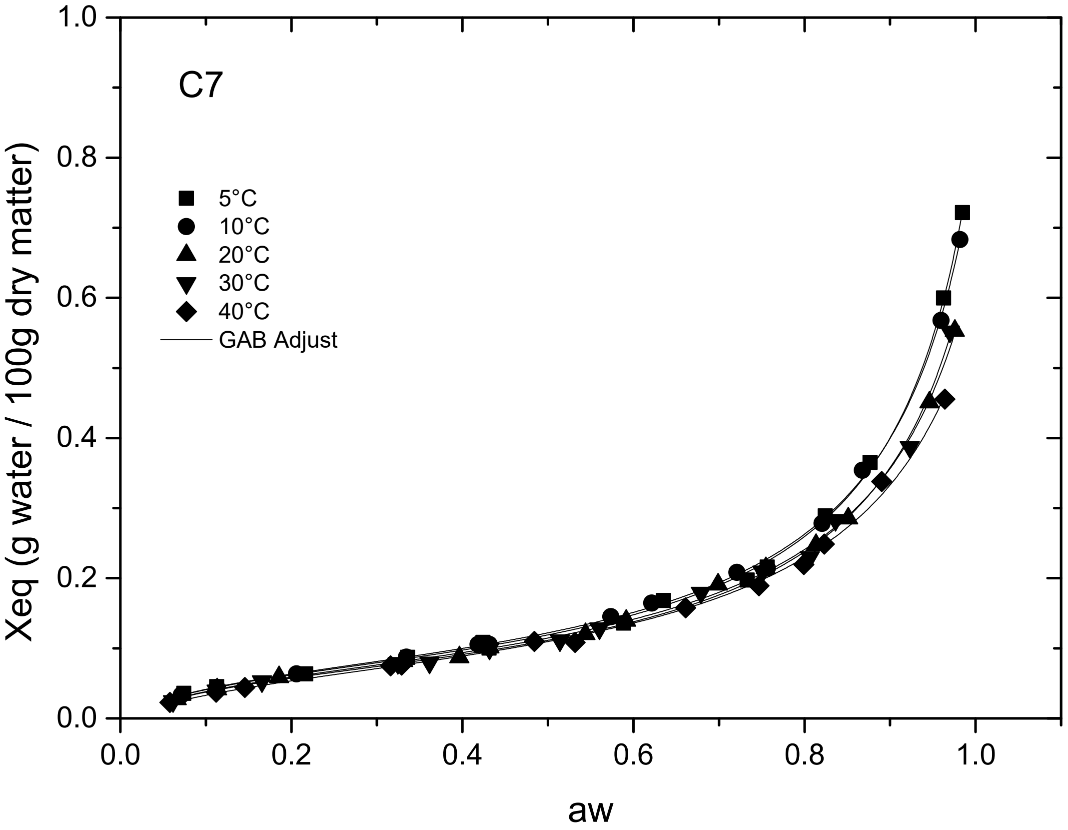

C4
5°C
10°C
20°C
30°C
40°C
GAB Adjust
Xeq (g water / 100g dry matter)
aw
0.0
0.2
0.4
0.6
0.8
1.0



C5
5°C
10°C
20°C
30°C
40°C
GAB Adjust
Xeq (g water / 100g dry matter)
aw
0.0
0.2
0.4
0.6
0.8
1.0



C6
5°C
10°C
20°C
30°C
40°C
GAB Adjust
Xeq (g water / 100g dry matter)
aw
0.0
0.2
0.4
0.6
0.8
1.0


C7
5°C
10°C
20°C
30°C
40°C
GAB Adjust
Xeq (g water / 100g dry matter)
aw
0.0
0.2
0.4
0.6
0.8
1.0

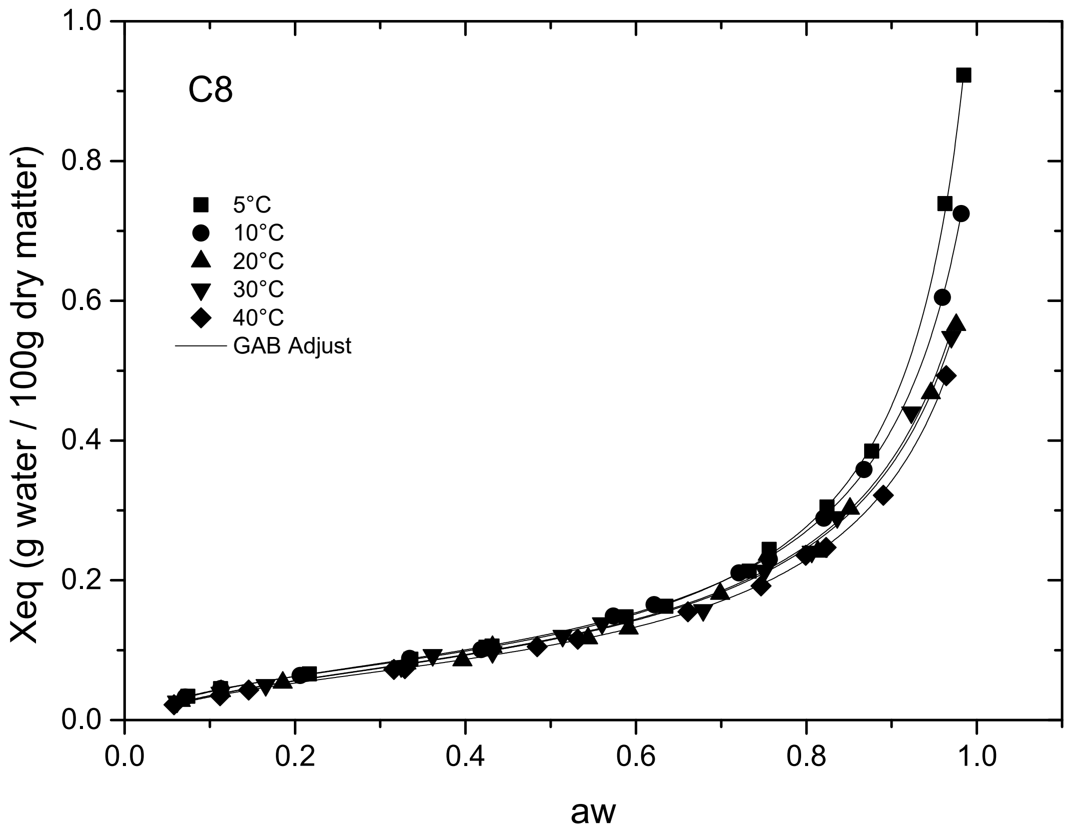
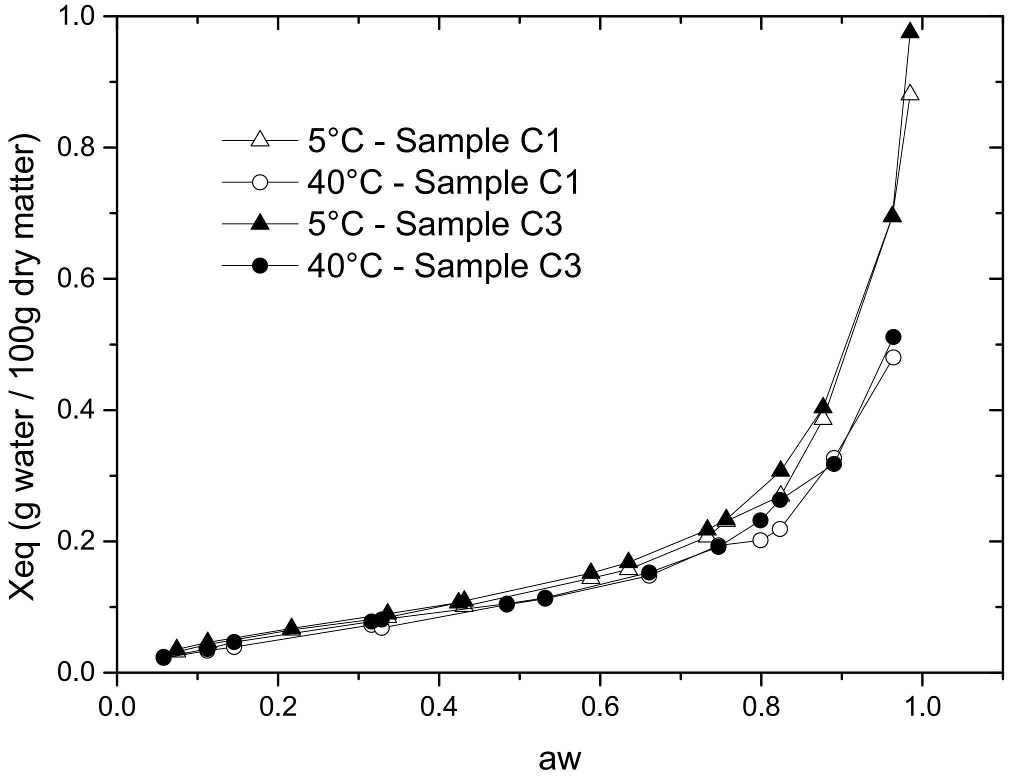

C8
5°C
10°C
20°C
30°C
40°C
GAB Adjust
Xeq (g water / 100g dry matter)
aw
0.0
0.2
0.4
0.6
0.8
1.0

Figure 2- Sorption isotherms of samples C1 and C3 at 5 and 40°C.



CONCLUSÃO GERAL

Este trabalho explorou a reformulação da copa para reduzir seu teor de sódio, uma necessidade evidenciada tanto pela demanda de consumidores quanto por diretrizes governamentais, considerando também a complexidade da produção deste produto cárneo de valor gastronômico e cultural. A investigação revelou que a variabilidade no teor de gordura, influenciada pela matéria-prima e diferenças anatômicas entre as carcaças, introduz desafios adicionais à análise, particularmente no que tange à heterogeneidade das sobrepaletas suínas e seu impacto nas propriedades físico-químicas e sensoriais do produto.

Foi possível uma redução de 40% no teor de sódio na copa, um avanço importante, mas ainda insuficiente para atingir as classificações de "baixo teor de sódio" e tampouco a de “reduzido teor de sódio” segundo Instrução Normativa nº 75, de 8 de outubro de 2020 da Agencia Nacional de Vigilância Sanitária do Brasil. A substituição de 50% do NaCl por uma mistura de KCl e $CaCl_2$, que não alterou as características sensoriais do produto, indica a viabilidade de produzir carnes curadas mais saudáveis. Este resultado sugere caminhos para futuras pesquisas, visando não apenas cumprir, mas também superar as diretrizes nutricionais atuais, por meio de novas formulações e técnicas de processamento que permitam reduções ainda maiores no teor de sódio.

A aplicação de isotermas de sorção ao estudo da copa comercial ajudou a compreender a interação entre a água e os componentes do produto, fundamental para otimizar o processamento e armazenamento e garantir a segurança alimentar. A análise de oito amostras comerciais de copa, utilizando o modelo GAB, mostrou variações na composição química e no conteúdo de sódio e destacou a influência da temperatura e do sódio na umidade de equilíbrio. Este achado sublinha a utilidade dos modelos matemáticos na indústria alimentícia, oferecendo percepção para aprimorar a qualidade, a estabilidade e a rentabilidade econômica dos produtos, além de fundamentar pesquisas futuras voltadas à adequação dos produtos às preferências dos consumidores.

Portanto, os estudos realizados contribuíram para um melhor entendimento da produção de copa, apontando os desafios e as variáveis críticas no processo. As descobertas fornecem percepções úteis para a indústria de alimentos, indicando estratégias para otimizar formulações no intuito de melhorar a qualidade e aumentar o apelo saudável dos produtos cárneos curados a seco, mesmo diante das limitações causadas pela falta de bibliografia específica sobre o assunto.