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DJALMA VITORINO COSTA FILHO

QUALIDADE DA CARNE DE FRANGOS ACOMETIDOS PELA MIOPATIA WHITE STRIPING (WS) ARMAZENADOS SOB REFRIGERAÇÃO E CONGELAMENTO

JOÃO PESSOA-PB

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Dissertação apresentada ao Programa de Pós-Graduação em Ciência e Tecnologia de Alimentos, Centro de Tecnologia, Universidade Federal da Paraíba, em cumprimento aos requisitos para obtenção do título de Mestre em Ciência e Tecnologia de Alimentos.

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A Deus, que é Amor puro e bondade.

Dedico.

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“O pessimista reclama do vento,
o otimista espera que ele mude,
o realista ajusta as velas.”

Provérbio Chinês.

RESUMO

O objetivo deste estudo foi entender, em que medida, a qualidade de filés de peito de frango WS severo é afetado pelo armazenamento sob condições de refrigeração e congelamento, em relação aos parâmetros físico-químicos, sensorial e aromático, juntamente com os danos oxidativos de sua fração lipídica e proteica. Os peitos de frango foram selecionados segundo o aspecto visual do músculo *Pectoralis major* em WS severo (apresentando estrias brancas de espessura superior a 1mm) e N (sem estrias brancas na superfície). Em seguida, os peitos foram seccionados em filés e armazenados em condições de refrigeração (±1 °C) por até 14 dias e congelamento (± -18 ºC) por até 90 dias. Os filés WS apresentam maior teor de lipídeos. Os filés WS e N refrigerados apresentaram queda no pH durante a refrigeração. A força de cisalhamento (FC) não diferiu entre as amostras WS e N; no entanto, houve uma redução significativa no valor da FC nos tempos 11 e 14 dias de acondicionamento sobre refrigeração, e nos tempos 45 e 90 dias em condições de congelamento. Em relação aos danos oxidativos, observou-se redução nos níveis de malondialdeído (MDA) e carbonila, além da interação desses compostos com outros compostos em filés crus, assados e reaquecidos sob armazenamento refrigerado (14 dias). A condição de congelamento reduziu significativamente o pH, força de cisalhamento e intensidade de amarelo (b*) dos filés WS e N sem alterar o teor de umidade, mantendo os níveis oxidativos dos filés WS em uma faixa de MDA que leva à formação de sabores e odores desagradáveis, que podem ser percebidos pelos consumidores. O maior teor de carbonilas nos filés WS em relação aos filés N impacta negativamente a qualidade do produto (perda de aminoácidos essenciais) e sua digestibilidade. O número e a concentração de compostos voláteis, em todo o período de armazenamento, refrigerado e congelado, foram superiores nos filés WS crus em comparação com filés N, mesmo ocorrendo uma redução no final do período de armazenamento. Os compostos voláteis de maior contribuição foram os aldeídos, independentemente do tipo de filé analisado e condição de armazenamento. O perfil de voláteis das carnes N e WS assadas, foi superior ao dos filés crus no tempo 0 dia de armazenamento, apresentando redução significativa após 11 dias em refrigeração, sem alteração quando submetido ao congelamento por 90 dias. Observou-se o efeito positivo e conservador nos voláteis no peito WS quando armazenados sob congelamento, diferente do observado com a carne N, que teve decréscimo do perfil de voláteis. Ao longo do armazenamento refrigerado e congelado os avaliadores perceberam sensorialmente um odor característico de frango fresco mais intenso para os filés N e WS, quando avaliados crus ou assados, embora se tenha observado uma redução no odor de frango fresco do peito WS cru aos 11 dias de refrigeração e aos 90 dias de congelamento. Logo, recomenda-se que as carnes sejam armazenadas sob refrigeração e consumidas dentro do período de até 11 dias para que as propriedades sejam mantidas para consumo.

PALAVRAS-CHAVE: Aroma, Peito estriado, Oxidação Lipídica. Oxidação Proteica, Qualidade.

ABSTRACT

The objectives of this study were to understand to what extent the quality of severe WS chicken breast fillets is affected by storage under refrigeration and freezing conditions, in relation to physicochemical, sensory and aromatic parameters, together with the oxidative damage of lipid and protein. Chicken breasts were selected according to the visual appearance of the *Pectoralis major* muscle in severe WS (with white streaks greater than 1mm thick) and N (without white streaks on the surface). Then, the breasts were sectioned into fillets and stored under refrigeration conditions (±1 °C) for up to 14 days and freezing (± -18 °C) for up to 90 days. WS fillets have higher lipid content. WS and N fillets showed a drop in pH during refrigeration. The shear force (SF) did not differ between the WS and N samples; however, there was a significant reduction in the SF value at 11 and 14 days of storage under refrigeration, and at 45 and 90 days under freezing conditions. Regarding oxidative damage, a reduction in malondialdehyde (MDA) and carbonyl levels was observed, in addition to the interaction of these compounds with other compounds in raw, roasted and reheated fillets under refrigerated storage (14 days). The freezing condition significantly reduced the pH, SF and yellow intensity (b*) of the WS and N fillets without changing the moisture content, keeping the oxidative levels of the WS fillets in an MDA range that leads to the formation of flavors and unpleasant odors, which can be perceived by consumers. The higher content of carbonyls in the WS fillets in relation to the N fillets has a negative impact on the quality of the product (loss of essential amino acids) and on its digestibility. The number and concentration of volatile compounds, throughout the storage period, refrigerated and frozen, were higher in raw WS fillets compared to N fillets, even though there was a reduction at the end of the storage period. The volatile compounds with the greatest contribution were aldehydes, regardless of the type of fillet analyzed and storage condition. The volatile profile of the roasted N and WS meats was superior to that of the raw fillets at 0 days of storage, showing a significant reduction after 11 days in refrigeration, with no change when subjected to freezing for 90 days. A positive and conservative effect was observed on volatiles in WS breast when stored under freezing, different from that observed with N meat, which had a decrease in the volatile profile. During refrigerated and frozen storage, the sensory evaluator perceived a more intense characteristic odor of fresh chicken for the N and WS fillets, when evaluated raw or roasted, although a reduction in the odor of fresh chicken from the raw WS breast was observed at 11 days of refrigeration and 90 days of freezing. Therefore, it is recommended that the meats be stored under refrigeration and consumed within a period of up to 11 days so that the properties of the meats are maintained for consumption.

KEYWORDS: Aroma, striated breast, Lipid oxidation. Protein Oxidation, Quality.

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LISTA DE ABREVIATURAS E SIGLAS

a*	Componente da cor vermelho-verde
ABPA	Associação Brasileira de Proteína Animal
ANOVA	Análise de Variância
b*	Componente da cor amarelo-azul
DIPOA	Departamento de Inspeção de Produtos de Origem Animal
DNPH	Dinitrofenilhidrazina
cm	Centímetro
FAO	Organização das Nações Unidas para Agricultura e Alimentação
FC	Força de cisalhamento
Kg	Quilogramas
L*	Luminosidade
MDA	Malonaldeído
ml	Mililitro
N	Normal
ng	Nanogramas
OAV	Valor de Atividade do Odor
pH	Potencial hidrogeniônico
PM	*Pectoralis major*
SIF	Serviço de Inspeção Federal
SM	*Spagheti Meat*
TBARS	Substâncias reativas ao ácido tiobarbitúrico
WOF	Aroma Requentado (*Warmed-over flavor*)
WB	*Wooden Breast*
WS	*White Striping*

SUMÁRIO

1. INTRODUÇÃO

Em 2021 a carne de frango teve um aumento de 9% em sua produção em relação a 2020, considerando produtos *in natura* e processados (ABPA, 2022); com um aumento de 17,1% no preço da carne, justificada pelo aumento da demanda global (FAO, 2021). Além disso, foram produzidas 100,4 milhões de toneladas de carne de frango no mundo e, destes, o Brasil contribuiu com uma parcela de 13,8 milhões de toneladas, fazendo jus a posição de terceiro maior produtor e maior exportador mundial de carne de frango (ABPA, 2021).

Embora haja o aumento da produção de carne de frango decorrente do aumento da demanda de consumo, a indústria avícola enfrenta ocorrências de anormalidades na carne devido a fatores de pré-abate e pós-abate (KUTTAPPAN; HARGIS; OWENS, 2016). Algumas anormalidades são específicas da carne de aves, acometendo em geral o músculo peitoral maior do frango, a exemplo das miopatias denominadas por peito estriado (*White Striping* - WS), peito amadeirado (*Wooden Breast* - WB) (KUTTAPPAN; HARGIS; OWENS, 2016; TIJARE et al., 2016; PETRACCI et al., 2019) e peito desfiado (*Spaghetti Meat* - SM) (BALDI et al., 2019; PETRACCI et al., 2019). Esses defeitos não apenas alteram a aparência visual, embora seja o primeiro critério em contato ao consumidor do músculo carne, mas também modificam a composição química e suas características histológicas e tecnológicas (GRATTA et al., 2019).

O peito WS é facilmente reconhecido pela ocorrência de estrias brancas seguindo a mesma direção das fibras musculares no peito de aves (PETRACCI et al., 2019). Um exame microscópico dessas faixas brancas revelou o acúmulo de lipídios e a proliferação de tecido conjuntivo (KUTTAPPAN et al., 2013). Peitos com miopatias WS, podem ser classificados em vários graus. Filés Normais não apresentam nenhuma estria no *Pectoralis Major* – PM. Os filés classificados como Moderados se apresentam com estrias paralelas às fibras musculares menores do que 1mm de espessura visíveis na superfície dos filés de peito. Já os filés classificados como Severos se apresentara com estrias geralmente maiores do que 1mm, largas e facilmente visíveis em sua superfície (PETRACCI et al., 2019).

Comparada à carne de outras espécies, a carne de aves é caracterizada por um maior teor de ácidos graxos insaturados que são especialmente suscetíveis a processos de oxidação, bem como pela presença de microrganismos deteriorantes. Consequentemente, a maioria da carne de frango é ofertada para fins culinários, nos mercados domésticos, sob resfriamento ou congelamento.

Embora o congelamento seja uma prática bem conhecida e amplamente usada para prolongar o prazo de validade das carnes, os efeitos do congelamento e descongelamento na qualidade das carnes continuam sendo um problema significativo devido às complexas alterações físicas, químicas e bioquímicas durante os processos, incluindo fusão de cristais de gelo, relaxamento de lipídios, proteólise de proteínas (LIU; CHEN, 2001; SOGLIA et al., 2019).

Segundo Estévez (2011), reações oxidativas podem ocorrer durante o armazenamento congelado da carne, tendo proteínas e lipídios como alvo principal. Além disso, a oxidação de proteínas e de lipídios estão diretamente interligadas. Grebenteuch et al. (2021), destacam que a oxidação de lipídios resulta na formação de compostos voláteis, principalmente aldeídos, álcoois, cetonas e alcanos, responsáveis pela perda de qualidade do alimento. Além do mais, Estévez, Ventanas e Heinonen (2011), destacaram as porções carbonil dos semialdeídos α-aminoadípicos e γ-glutâmicos (AAS e GGS, respectivamente), ambos produtos da degradação oxidativa de proteínas específicas, podem reagir com o grupo amino de aminoácidos livres (leucina e isoleucina), e formar estruturas de base de Schiff e, eventualmente, desencadear a formação dos aldeídos de Strecker, que são precursores de aroma da reação de Maillard.

O perfil aromático de carnes, como de frango, de bovino, de suínos e de pescado são amplamente conhecidos. No entanto, poucos são os estudos que discutem os mecanismos envolvidos nas mudanças de peito de frango em decorrência da miopatia WS (KUTTAPPAN; HARGIS; OWENS, 2016), e que pouco se sabe sobre a qualidade das carnes WS, e as alterações que ocorrem nelas ao longo do armazenamento resfriado e congelado (DALGAARD et al., 2018; GRATTA et al., 2019; SOGLIA et al., 2017).

Chmiel et al., (2020) avaliando os compostos voláteis de filés de frango em diferentes tempos e temperatura de armazenamento, reportaram que o perfil de voláteis não sofreu influência no período de avaliação. Entretanto, estudos sobre o perfil volátil de peitos acometidos de WS não existem.

Logo, os objetivos deste estudo foram entender em que medida a qualidade da carne de peito de frango WS é afetado pelo armazenamento sob condições de refrigeração e congelamento, analisando-se os parâmetros físico-químicos e sensoriais, perfis de aromas e de oxidação lipídica e proteica.

2. REVISÃO DE LITERATURA

2.1 WHITE STRIPING (WS)

De acordo com o Departamento de Inspeção de Produtos de Origem Animal (DIPOA), através do Ofício Circular nº 17, de 13 de dezembro de 2019, a miopatia *White Striping* (WS), se caracteriza pelo surgimento de estrias esbranquiçadas na superfície do *Pectoralis major* (PM) de frangos, afetados principalmente na região cranial, podendo se estender por todo o músculo (BRASIL, 2019).

Baldi et al., (2019) relata que WS é uma condição caracterizada pela ocorrência de estrias brancas paralelas às fibras musculares no peito, na coxa e nos músculos sensíveis de frangos. Esta condição é histologicamente caracterizada como miodegeneração e necrose, fibrose, lipidose e mudanças regenerativas. As estrias aparecem como "cicatrizes" e são identificadas principalmente como um acúmulo de lipídios (lipidose) e tecido conjuntivo (fibrose) (BALDI; SOGLIA; PETRACCI, 2020; KUTTAPPAN; HARGIS; OWENS, 2016).

A miopatia WS é facilmente reconhecida pela ocorrência de estrias brancas seguindo a mesma direção das fibras musculares do PM (PETRACCI et al., 2019; TASONIERO et al., 2016; TIJARE et al., 2016). A miopatia WS pode ocorrer conjuntamente, ao mesmo tempo e no mesmo músculo, com a miopatia de peito amadeirado (*Wooden Breast* – WB), que é uma miopatia que causa uma aparência pálida, rígida, inchada e pode ter exsudato viscoso e hemorragias na superfície do filé. Nesta ocorrência, estes compartilham características histológicas comuns (BALDI et al., 2018). A extrema deposição de colágeno, juntamente com o acúmulo de fibrilas de colágeno reticuladas ocasionada pelo WS, pode ser a causa da rigidez dos músculos WB (SOGLIA, F. et al., 2017).

Carvalho et al. (2020) investigando os mecanismos moleculares envolvidos no aparecimento da *White Striping* Severa (WS-S) com particular atenção ao papel do estresse oxidativo e da oxidação de proteínas na perda de qualidade da carne, verificaram que a miopatia WS, apresentou maior pH, dureza, vermelhidão, conteúdo de lipídios e colágeno e menor leveza do que o peito normal. Ainda, WS-S teve uma perda mais severa de tióis de proteína (70,7% menos tióis do que em N), atividade reduzida de enzimas antioxidantes como a catalase (23 contra 40 U g^{-1}), glutationa peroxidase (0,21 contra 0,54 U g^{-1}) e superóxido dismutase (56 contra 73 U g^{-1}) e, consequentemente, teve maior acúmulo de substâncias reativas ao ácido

tiobarbitúrico (0,64 versus 0,22 mg MDAkg $^{-1}$ músculo), alisina (3,1 versus 1,9 nmol mg $^{-1}$proteína) e estruturas de base de Schiff (645 versus 258 unidades fluorescentes).

Na Figura 1 é apresentado um panorama geral da miopatia WS e o grau de comprometimento do peito de frango. O grau de severidade varia e um sistema básico de classificação que categoriza os filés de peito visualmente entre normais (N), moderados (WS-M) ou severos (WS-S) foram sugeridos por Owens e Vieira (2012).

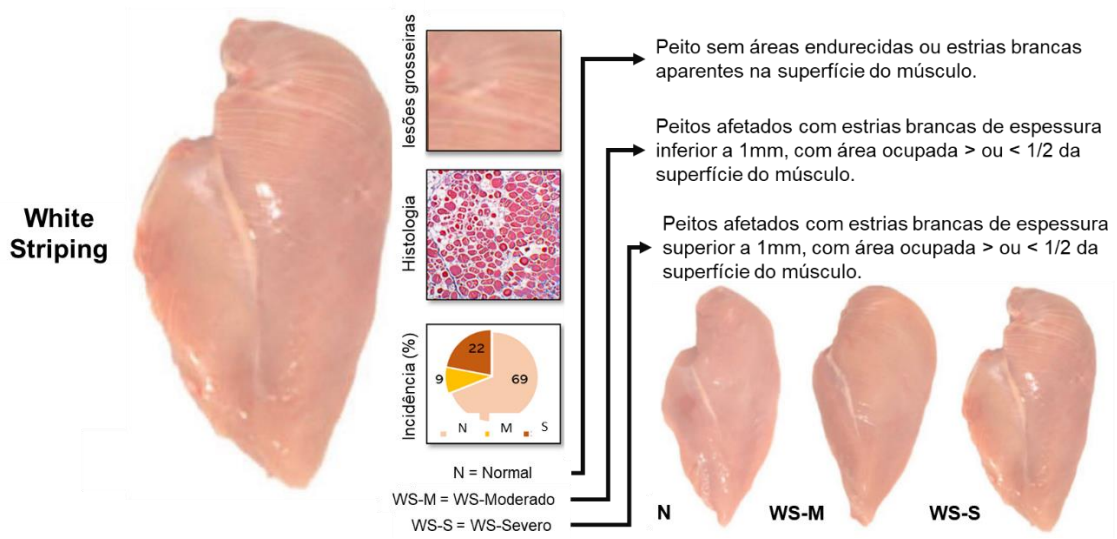


Figura 1 - Esquema relatando imagens representativas de características macroscópicas e microscópicas e os dados relativos aos níveis de incidência de caso normal (N ➔ sem estrias), moderado (WS-M ➔ estriações <1 mm) e severo (WS-S ➔ estrias> 1 mm).

Fonte: Adaptado de Kuttappan et al. (2013), Soglia et al. (2017) e Baldi et al. (2018).

As estrias brancas na superfície da carne afetam a avaliação visual ainda na gôndola dos supermercados a qual prejudica a comercialização dos peitos de frango *in natura* (KATO et al., 2019). Ou seja, esta miopatia afeta negativamente as propriedades sensoriais e físicas do peito, levando a redução da aceitação pelo consumidor, perda tecnológica e financeira (PETRACCI et al. 2013; KUTTAPPAN et al., 2016). Esse problema é de grande importância para a indústria da carne de frango como retrata o estudo de Kuttappan et al., (2012), os quais observaram o impacto que a ocorrência de WS possui sobre a aceitação dos peitos de frango pelos consumidores, segundo estes autores 50% das respostas foram de que "provavelmente ou definitivamente não comprariam" os peitos acometidos em níveis moderados ou severos.

Segundo Kindlein et al. (2017) a miopatia WS é resultado da seleção genética dos frangos de corte para crescimento mais rápido e aumento da produção de peito que desencadeia

a hipóxia localizada. Sua ocorrência tem sido associada ao aumento da taxa de crescimento das aves (BAÉZA; GUILLIER; PETRACCI, 2021; BALDI; SOGLIA; PETRACCI, 2020; KUTTAPPAN et al., 2012). Estudando o efeito de diferentes níveis de vitamina E na dieta sobre a incidência de WS, Kuttappan et al., (2012) relataram que a vitamina E não teve efeito na ocorrência de listras brancas. Estes fatores de risco citados para WS em frangos de corte são frequentemente destacados, exceto os relacionados ao meio ambiente (BALDI et al., 2018).

Estudos relacionados aos aspectos proteômicos revelam alterações no metabolismo de carboidratos e proteínas associadas à miopatia de peitos de frango com WS (KUTTAPPAN et al., 2017).

2.2 PERFIL SENSORIAL DE CARNES DE FRANGO

Carnes e seus derivados constituem uma importante fonte de proteína na dieta do homem e sua ingestão é determinada por fatores socioeconômicos, questões éticas, crenças religiosas e tradição (FONT-I-FURNOLS e GUERRERO, 2014). O consumo continuado de carne e produtos cárneos pode ser garantido por meio de um fornecimento de carne saborosa, nutritiva e segura para os consumidores (JOO e KIM, 2011).

O gosto da carne compreende principalmente sabor e aroma e envolve o comportamento e preferências de compra de carne dos consumidores, mesmo antes de a carne ser consumida (SITZ et al., 2005).

A vida útil de carnes é geralmente determinada por seus atributos sensoriais de aparência, textura, cor, sabor, pela atividade microbiana e pelo valor nutritivo (ALI et al., 2015). Quanto a carne de frango, atualmente, os consumidores exigem mais variedade de cortes finos e de qualidade (AMORIM et al., 2015).

De acordo com Franke et al. (2017) a aceitação sensorial é o critério-chave para os consumidores que julgam o frescor da carne de frango. Especialmente antes de qualquer preparação, a impressão sensorial é o fator decisivo para o processamento posterior ou qualquer forma de consumo. Segundo Mir et al. (2017), a aparência é o mais importante atributo de qualidade da carne de frango cozida ou crua, pois os consumidores associam com o frescor do produto e decidem se compram ou não o produto com base em sua opinião sobre sua atratividade.

Os atributos aparência, aroma e sabor da carne estão ligados à memória sensorial dos consumidores e associadas a aceitação ou rejeição do produto, uma vez que, aparência e aroma

despertam o consumo e o sabor interage com as sensações do gosto e ao aroma (ASSUNÇÃO et al., 2017).

Muitos estudos foram realizados enfocando as análises sensoriais de carne de diferentes espécies animais, contudo, a comparação dos resultados sensoriais de diferentes estudos necessita de critérios, considerando as variações no preparo das amostras, o tempo de armazenamento, o corte, os métodos estatísticos utilizados, etc. (RØDBOTTEN et al., 2004).

Quanto a textura, Mir et al. (2017) destacam que se trata do atributo de qualidade mais importante relacionado à satisfação do consumidor na qualidade alimentar de carne de aves, uma vez que é fortemente impactada em função da quantidade de água retida por via intramuscular. Nesse sentido, ressalta-se que a maciez da carne de frango sofre influência do estresse ambiental durante o processo de criação, já que aves submetidas a estresse prolongado tem um rápido gasto das reservas de glicogênio durante o abate, propiciando carne mais rígida e menos suculenta (ASSUNÇÃO et al., 2017).

As diferenças encontradas entre os cortes de frango (peito, coxa, sobrecoxa) são consequentes do tipo da fibra e do metabolismo em cada porção do músculo (MENDES, 2019). Em estudo para comparar perfis sensoriais descritivos de peito de frango categorizado em leve, médio e pesado (peitoral maior) desossado, sem pele e cozido, foram observadas diferenças na intensidade de textura descritiva sensorial e atributos de sabor, coesão, dureza, suculência e acidez (ZHUANG; SAVAGE, 2012).

Ressalta-se que, além do peso dos filés de peito de frango, o genótipo, a idade e a técnica de processamento podem, isoladamente ou combinados, afetar significativamente a funcionalidade da carne e sua qualidade sensorial (ZHUANG; SAVAGE, 2012). Ademais, avaliações subjetivas são mais relevantes para as preferências do consumidor em relação às escolhas alimentares, entretanto, as escolhas dos consumidores baseiam-se em muitos fatores que nem sempre estão relacionados aos atributos sensoriais, como cor da carne cozida ou suculência percebida (SMITH; NOTHCUTT; STEINBERG, 2012).

Em estudo para verificar se havia diferença sensorial entre o descongelamento rápido e lento de filés de frango e se a fritura antes ou após o descongelamento interferia na aparência global do produto, foi observado que o uso de forno micro-ondas para o descongelamento rápido dos filés proporcionou melhoria nas características sensoriais do produto, em comparação ao descongelamento sob refrigeração, entretanto não se observaram diferenças entre os dois modos de descongelamento dos filés previamente fritos (MANTILLA; POMBO; FREITAS, 2010).

Ao avaliar as propriedades sensoriais da carne crua de frango embalada em duas condições atmosféricas diferentes ("CO_2(30)": 30/70% CO_2/O_2 e "CO_2(15)": 15/85% CO_2/O_2) Franke et al. (2017) observaram que a composição da atmosfera modificada influencia a impressão sensorial, e que os atributos impressão visual geral e impressão ortonasal geral podem ser utilizados como indicadores de deterioração da carne de frango sob atmosfera modificada.

Komiyama et al. (2010) ao avaliar a qualidade de propriedades físico-químicas, funcionais e sensoriais de carne de matriz pesada em final de ciclo produtivo, verificando se esta poderia ser comercializada *in natura*, estes autores observaram menor alteração de aroma, baixa intensidade de maciez, menor suculência e mais elasticidade, maior aspecto borrachudo e mais dificuldade de deglutir do que a carne de peito de frango de corte.

De acordo com Zhuang e Savage et al (2012), a seleção genética feita atualmente com as linhagens de frango, baseada na taxa de crescimento e eficiência alimentar, pode sacrificar a qualidade da carne de peito. Contudo, não se sabe se as diferenças na avaliação sensorial descritiva podem ser percebidas pelos consumidores, podendo não ser importantes para a aceitação geral da carne de peito de frango cozida.

Ao avaliar o grau de conhecimento, aceitabilidade e intenção de compra dos consumidores de peitos de frango afetados pela miopatia WS, Carvalho et al. (2020), observaram-se menores graus de aceitabilidade e intenção de compra, quando informados da condição de peitos com a miopatia, em comparação aos peitos normal. Além disso, o perfil emocional dos consumidores dos consumidores foi afetado pela conscientização da miopatia WS, uma vez que os mesmos se sentiam menos "bem-humorados", "amorosos" e "amistosos", e mais "interessados" e "entusiasmados" ao consumir filés de frango com estrias.

Modificações aparentes na carne de aves, tais quais o aparecimento de estrias brancas na superfície de peitos de frango (típico da miopatia WS), apresenta um impacto negativo sobre a aceitabilidade e intenção de compra, já que altera a percepção de qualidade do produto pelo consumidor no ato da compra.

2.3 PERFIL DE VOLÁTEIS NA CARNE DE FRANGO

Os compostos voláteis da carne de frango são dependentes de precursores-chave e vários fatores incluindo fatores genéticos, sexo, idade, dieta e também como diferentes fatores de processamento, como congelamento, refrigeração, pré-embalagem, cozinhar, desidratação,

procedimentos de irradiação e armazenamento (RAMASWAMY e RICHARDS, 1982). Já o tratamento térmico inicia uma série de reações que resultam no desenvolvimento do sabor característico da carne. Essas reações são multidirecionais e incluem: reações de Maillard, oxidação de lipídios, interações entre produtos de reação de Maillard e produtos de oxidação de lipídios, bem como degradação de tiamina (MACLEOD, 1998). O tratamento térmico de carnes magras (bovina, suína, de aves e de cordeiro) proporciona um sabor de carne não específico da espécie, enquanto o aquecimento da carne contendo gordura, especialmente fosfolipídios e, em menor extensão, triglicerídeos, causa o desenvolvimento de um sabor de carne específico da espécie (KOSOWSKA; MAJCHER e FORTUNA, 2017).

Numerosos compostos voláteis são gerados durante o processamento térmico que pertencem a várias classes químicas: hidrocarbonetos, álcoois, aldeídos, cetonas, ácidos carboxílicos, ésteres, lactonas, furanos, pirranos, pirroles, pirazinas, piridinas, fenóis, tiofenos, tiazóis, tiazolinas, oxazoles e outros compostos de nitrogênio ou sulfúrico. O sabor específico da espécie da carne é determinado por misturas de compostos voláteis que, no caso de produtos tratados termicamente, podem incluir até algumas centenas de compostos, por exemplo, cerca de 880 compostos voláteis foram identificados na carne cozida (MOTTRAM, 1994).

A contribuição de compostos voláteis individuais no desenvolvimento do sabor característico da carne cozida varia em função de diferentes fatores (produção do animal - raça, castração, idade de abate, das condições de cozimento, etc). Apenas uma pequena parte desse vasto número de compostos voláteis que ocorrem em produtos alimentícios contribui para o desenvolvimento do sabor cárneo. Portanto, é extremamente importante separar os compostos aromáticos ativos dos outros constituintes dos alimentos inodoros (KOSOWSKA; MAJCHER e FORTUNA, 2017). Em geral, estima-se que apenas 3% dos 10.000 compostos voláteis identificados são capazes de transmitir odores a produtos alimentícios (HOFMANN et al., 2014).

Grande parte dos trabalhos presentes na literatura estuda o perfil de voláteis na carne após a cocção. Porém Ayseli, Filik e Selli (2014) determinaram o perfil de voláteis no peito de frango cru. Um total de 33 compostos foram identificados e quantificados na carne de peito de frango, totalizando uma concentração de 536,1 µg/kg de compostos voláteis, incluindo voláteis ácidos (8), ésteres (4), álcoois (8), cetonas (4), aldeídos (4), fenóis (4) e terpeno (1). De todos os 33 compostos voláteis encontrados no peito de frango cru, apenas três apresentaram um valor de atividade de odor (OAV) alto o suficiente para mostrar-se relevante na determinação do aroma e sabor (OAV>1) (AYSELI, FILIK E SELLI, 2014).

O OAV é definido como a relação entre a concentração e o limiar de odor, fornecendo uma ideia da potência aromática de um único odorante em um alimento, com base em seu limiar de odor na respectiva matriz alimentar (SELLI e CAYHAN, 2009; GENGJUN; HUANLU e CHANGWEI, 2009). Desta forma, os compostos voláteis que se mostram representativos no perfil de aroma e sabor do peito de frango cru foram hexanal (odor fresco e verde), o (E)-2-heptanal (odor verde de queijo e gorduroso) e o 4-vinil-2-metoxifenol (odor picante) (AYSELI, FILIK E SELLI, 2014).

Quanto a carne de frango cozida, muitos de seus principais compostos de sabor e odor, juntamente com os mecanismos para a formação, foram identificados (ALIANI e FARMER, 2005). De acordo com Shi e Ho (1994) dezesseis componentes primários de odor foram identificados no caldo de galinha, dos quais quatorze estão estruturalmente identificados. Eles demonstraram ainda que o 2-metil-3-furantiol, gerado a partir da reação de Maillard e da oxidação lipídica, é o composto químico mais vital e responsável pelo sabor de carne do caldo de galinha.

Além disso, outros compostos voláteis originados das reações de Maillard e Oxidação de Lipídeos, incluem 2-furfuriltiol, metionol, 2,4,5-trimetiltiazol, nonanol, 2-trans-nonenal, 2-formil-5-metiltiofeno, p-cresol, 2-trans-4-trans-nonadienal, 2-trans-4-trans-decadienal, 2-undecenal, β-ionona, γ-decalactona e γ-dodecalactona. Esses compostos são obviamente as principais fontes do sabor de frango (SHI e HO 1994; VARAVINITI et al., 2000). Em outro estudo, Sasaki et al. (2007) mostraram que componentes responsáveis pelas características umami contribuem para o sabor de caldo da carne. Com relação aos odores primários, 2-trans-4-trans-decadienal e γ-dodecalactona predominaram no caldo de galinha em comparação com o da carne bovina.

Semelhante a outras carnes, o desenvolvimento do sabor da carne de aves é parcialmente atribuído aos seus lipídios (PEREZ-ALVAREZ et al., 2010). Várias centenas de compostos voláteis são gerados na carne cozida por meio da degradação de lipídios, principalmente a oxidação dos componentes de ácidos graxos dos lipídios. Tais compostos incluem hidrocarbonetos alifáticos, aldeídos, álcoois, cetonas, ésteres, ácidos carboxílicos, alguns hidrocarbonetos aromáticos e compostos heterocíclicos oxigenados, tais como lactonas e alquilfuranos (MOTTRAM, 1998). De acordo com Jayasena et al. (2013) quarenta e um de um total de 193 compostos relatados no sabor de frango assado são aldeídos derivados de lipídios.

Não foram encontrados na literatura estudos sobre o perfil de compostos voláteis em peitos de frango acometidos pela miopatia WS. Porém, Tasoniero et al. (2016) traçaram um

perfil sensorial destas carnes, onde foi atribuído um perfil mais rançoso aos peitos de frango que possuíam algumas miopatias do que quando comparados ao normal.

2.4 EFEITO DO CONGELAMENTO E RESFRIAMENTO NA CARNE DE FRANGO

Enquanto os principais objetivos do resfriamento de aves são aumentar a segurança alimentar para os consumidores e estender a vida útil do produto para comercialização (SAMS, 2001), o congelamento é descrito como um método de conservação de alimentos comumente aceito para garantir a segurança dos produtos cárneos no mercado global de exportação de carne (LEYGONIE et al., 2012).

O resfriamento, quando realizado por imersão, pode afetar diretamente os nutrientes solúveis em água na carne de aves, sem impacto significativo nas proteínas ou lipídios. Porém, carnes de aves recém abatidas, se resfriadas e armazenadas em condições ideais, podem ter uma vida útil de 2-3 semanas, durante o resfriamento por imersão (MIR et al., 2017).

Fatores como contaminação cruzada, gerenciamento de águas residuais, remanejamento e perda de purga pós-resfriamento são desafios do método de resfriamento por imersão, porém, ele ainda é mais popular nos Estados Unidos em comparação ao resfriamento por ar, que é mais comum na Europa, Brasil e Canadá (DEMIROK et al., 2013; MIR et al., 2017).

Ambos os sistemas de resfriamento apresentam vantagens e desvantagens na qualidade e segurança dos frangos. Durante o resfriamento por imersão, as carcaças podem absorver água (4 a 6%) através da pele e da gordura circundante, em contraste com o resfriamento por ar, onde não há captação de umidade e até mesmo um rendimento negativo devido à perda excessiva de umidade (DEMIROK et al., 2013).

Sob condições adequadas de uso de refrigeração, poucas são as alterações na qualidade da carne, conforme observado por Zhuang e Savage (2009) para a cor, pH, força de cisalhamento ou capacidade de retenção de água e por Perumalla et al. (2011) nas propriedades de marinação, qualidade sensorial e tenacidade da carne de peito de frango submetida a diferentes métodos de resfriamento.

Além das propriedades sensoriais, do valor nutricional e da atividade microbiana, a vida útil de carnes é fortemente influenciada pelo armazenamento congelado e posterior descongelamento (ALI et al., 2015). Embora seja considerado uma forma branda de conservação, o congelamento é capaz de alterar características de qualidade através da formação dos cristais de gelo (OLIVEIRA et al., 2015).

Cristais de gelo formados durante o congelamento danificam a ultraestrutura e concentram os solutos na carne o que, por sua vez, leva a alterações nas reações bioquímicas que ocorrem em nível celular e influenciam os parâmetros de qualidade física da carne (LEYGONIE; BRITZ; HOFFMAN, 2012).

Os processos de degradação de lipídios e proteínas são os principais responsáveis pela deterioração de carnes congelada durante o armazenamento (ALI et al., 2015). Os parâmetros de qualidade mais influenciados pelos efeitos do congelamento e resfriamento de carnes são perda de umidade, desnaturação de proteínas, cor, pH, força de cisalhamento e deterioração microbiana (LEYGONIE; BRITZ; HOFFMAN, 2012).

A oxidação de lipídios e proteínas pode ocorrer simultaneamente na carne de frango durante o armazenamento congelado e ser mais intensa em coxas do que em peito de frango (SOYER et al., 2010). Maior grau de oxidação lipídica e proteica em peito de frango, evidenciado por altos teores de malondialdeído e compostos carbonila, e menores teores de grupos sulfidrila, foi observada durante o aumento dos ciclos de congelamento e descongelamento de peitos de frango (ALI et al., 2015).

A perda por gotejamento ou, mais apropriadamente, perda por descongelamento, é um dos atributos de qualidade mais frequentemente medidos em carnes porque pode levar a uma diminuição nos lucros dos processadores de carne (FRELKA et al. 2019).

Em estudo para avaliar os efeitos da temperatura de congelamento e a duração do armazenamento congelado na oxidação de lipídios e proteínas em coxas e peito de frango, Soyer et al. (2010) verificaram um efeito significativo da duração do armazenamento congelado na oxidação lipídica, porém sem diferença entre as temperaturas de -7, -12 e -18 °C. Os autores verificaram também que o congelamento a -7 °C impactou na oxidação de proteínas das coxas, aumentando os grupos carbonila e diminuindo os grupos sulfidrila totais, após 3 meses de armazenamento congelado.

Ao investigar os efeitos de ciclos repetidos de congelamento e descongelamento sobre peito de frango, Ali et al. (2015) observaram que os ciclos aumentam a oxidação de lipídios e proteínas, reduzindo a estabilidade da cor e o pH da carne de peito de frango e causaram mudanças estruturais na proteína muscular, diminuindo a capacidade dos músculos em reter água.

Peitos de frango descongelados após armazenamento congelado a −18 °C por diferentes períodos de tempo (1, 2, 3, 4, 5, 6, 7 e 8 meses) apresentaram diminuição na capacidade de retenção de água e da solubilidade da proteína, enquanto o teor de substâncias reativas ao ácido tiobarbitúrico aumentou com o aumento do tempo de armazenamento (WEI et al., 2017).

Em estudo para avaliar as alterações após descongelamento nas características físico-químicas e estruturais de peito de frango submetido ao congelamento rápido (-36 °C por 2 horas), Oliveira et al. (2015) observaram que descongelar os peitos de frango embalado em sacos de polietileno de baixa densidade e colocado em água fria (10 °C por 2 horas e 15 minutos) manteve a organização das fibras musculares e garantiu menor perda por gotejamento, maior teor de umidade e maior maciez da carne, garantindo menor perda por gotejamento, maior teor de umidade e maior maciez.

Em estudo para avaliar os efeitos do congelamento e recongelamento na composição química de carnes bovina e de aves no período de armazenamento 4,5 meses, Hammad et al. (2019) observaram que a carne de aves apresentou maiores teores de umidade, proteína e cinzas, mas menores teores de gordura do que a carne bovina. Os autores recomendam armazenar tais carnes (bovina e de frango) em temperatura de congelamento constante para evitar oscilações de temperatura e instabilidade na composição do produto. Além disso, salientam para a importância de se evitar recongelar uma carne completamente descongelada e de se embalar adequadamente as carnes congeladas para reduzir o espaço aéreo e seu efeito isolante, bem como, os altos custos de congelamento resultantes.

Pereira et al. (2022), em estudo que avaliou possíveis alterações na qualidade da carne de peito de frango contendo estrias brancas durante o congelamento por 12 meses, sugeriram que o processo de congelamento pode ser de grande importância para a avicultura, principalmente quando utilizado em peitos de frango acometidos pela miopatia de listras brancas. Esses autores verificaram que a miopatia associada ao congelamento resultou em aumento da maciez da carne, com redução da proteína bruta e da matéria mineral e aumento da umidade, gordura e colesterol, sem afetar os percentuais de colágeno da carne.

Tem-se ampliado o uso de métodos instrumentais para avaliar a qualidade de carnes congeladas, entre os quais a medição da impedância elétrica se destaca por ser rápida, não destrutiva e de fácil uso, podendo ser aplicada para avaliar parâmetros como pH, teor de gordura, maciez e frescor, tendo demonstrado potencial de avaliar a qualidade da carne de frango congelada combinada com índices de qualidade (WEI et al., 2017),

Perfis de calorimetria de varredura diferencial e padrões de bandas SDS-PAGE de proteínas miofibrilares indicaram ligeira desnaturação de miosina e actina com ciclos repetidos de congelamento-descongelamento (ALI et al., 2015).

Frelka et al. (2019) observaram, por medições com ressonância magnética, que as perdas na qualidade por descongelamento de peito de frango se correlacionam com as mudanças na

mobilidade e localização da água. Esses autores ressaltam ainda que o efeito das mudanças na mobilidade da água, é altamente dependente da interação com a fração de proteína na carne.

Entre os mecanismos que vem sendo empregados para mitigar os efeitos do congelamento e descongelamento estão o uso de novos métodos de congelamento e descongelamento, *ante* e *post mortem* inclusão de proteína anticongelante e suplementação de vitamina E, injeção de salmoura e embalagem atmosférica modificada (LEYGONIE; BRITZ; HOFFMAN, 2012).

A comercialização de produtos congelados prontos para o consumo e que podem se descongelados rapidamente em micro-ondas apresenta vantagens tanto para a indústria alimentícia, quanto para o consumidor por serem práticos e de fácil preparo, entretanto, com relação à aquisição de produtos como files de frango fritos e congelados nos mercados, fazem-se necessários mais estudos sobre as preferências dos consumidores. (MANTILLA; POMBO; FREITAS, 2010).

3. MATERIAL E MÉTODOS

3.1. MATÉRIA -PRIMA

3.1.1 Coleta e preparo de amostras

Os filés de peitos de frango da linhagem comercial Cobb®, machos e fêmeas, com idade de abate entre 42 e 46 dias foram coletados em um abatedouro do município de Nazaré da Mata, Zona da Mata Norte do estado de Pernambuco, com Selo de Inspeção Federal (SIF). Os peitos foram selecionados aleatoriamente logo após o abate e desossa. Foram coletados os filés de peito de frango Normal (N) (sem estrias brancas aparentes na superfície) e os acometidos pela miopatia '*Whie Striping*' (WS) com grau severo (com estrias brancas de espessura superior a 1mm). A classificação e identificação dos peitos em N e WS foi feita por observação do aspecto visual do músculo *Pectoralis major*, no que se refere a presença ou ausência de estrias, conforme descrito por Bailey et al. (2015a). Após a classificação, os filés WS severo e N foram colocados em sacos plásticos de polietileno com fechamento zip lock e, armazenados em caixa térmica, com gelo, e conduzidos a UFPB.

Um total de trinta peitos de frango (15 N e 15 WS) foram coletados para o estudo envolvendo a caracterização físico-química e níveis de oxidação lipídica e proteica, sendo que para cada tempo de armazenamento sob refrigeração ou congelamento foi reservado 3 peitos N e 3 WS. O tempo zero dia foi comum a ambos os tratamentos de armazenamento.

Já para o estudo envolvendo análise sensorial e perfil de voláteis, igual quantidade de peitos foram coletados (n=30; 15 N e 15 WB), sendo para cada tempo de armazenamento sob refrigeração (t = 0, 11 e 14 dias) reservados 3 peitos N e 3 WS, e para congelamento (t= 0, 45 e 90 dias) reservados igual quantidade. O tempo zero dia foi comum a ambos os tratamentos. No entanto, a avaliação sensorial só ocorreu no tempo 0, t=11 (refrigeração) e t=90 dias (congelamento). Todo o experimento foi realizado três vezes.

No Laboratório de Análises Químicas de Alimentos (LAQA/CT/UFPB), os peitos foram limpos do excesso de gordura, fragmentos de ossos e tecido conectivo, identificados e armazenados sob refrigeração (± 1 °C) por até 14 dias onde foram analisados nos tempos 0, 11 e 14 dias; e congelamento (-18ºC) por até 90 dias, com analises nos tempos 0, 45 e 90 dias.

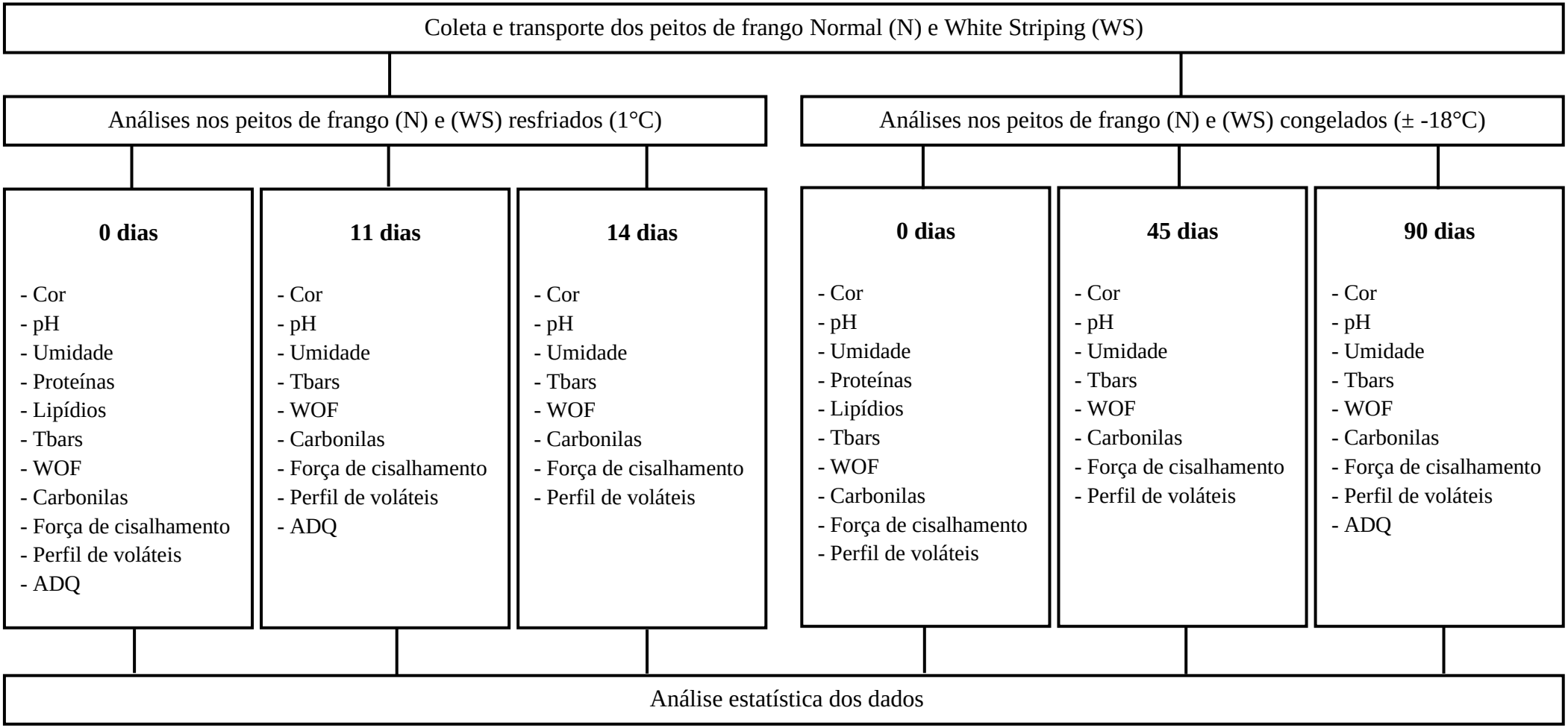
Optou-se por estes intervalos de tempo (14 dias sob refrigeração e 90 dias sob congelamento) considerando as recomendações dos abatedouros e as práticas domesticas de consumo, que utilizam em geral o armazenamento de até 14 dias para peito de frango resfriado, e em média de 90 dias para peito de frango congelado.

No ato das análises, a porção direita do filé de peito de frango foi destinada para a caracterização das amostras cruas, e a porção esquerda foi reservada para a caracterização dos filés assados. Os filés foram assados em forno a gás pré-aquecido a 180 ºC, e removidos quando os mesmos apresentaram a temperatura interna igual a 75 ºC (SOULTOS et al. 2008). A temperatura do forno e a temperatura interna dos peitos foi controlada por meio de termopar (Hanna Instruments Inc., HI 9350005, Romênia). Igual condição de processamento térmico foi adaptada para os peitos destinados as análises físico-químicas, sensorial e de perfil de aroma (analise de voláteis).

3.1.2 Caracterização dos filés de peito de frango

Os filés de peito de frango avaliados como N e WS, foram submetidos às análises físico-químicas (pH, cor, umidade, proteínas e lipídios, força de cisalhamento), qualidade oxidativas (TBARS, aroma requentado, e carbonilas), análise sensorial (ADQ) e de perfil de compostos voláteis, conforme apresentação do delineamento experimental na Figura 2.

Figura 2 – Delineamento experimental do estudo.



Fonte: Próprio autor.

3.2 MÉTODOS ANÁLITICOS

3.2.1 Caracterização físico-química

A composição química foi determinada dos peitos crus seguindo metodologias descritas pela AOAC (2000) para teor de umidade (nº 950.46.41), proteínas (nº 928.08). Para determinação do teor de lipídios será utilizada a metodologia descrita por Folch, Less e Stanley (1957). O pH foi determinado utilizando um pHmetro Modelo Q400 AS (Quimis Aparelhos Científicos Ltda., Diadema, SP, Brasil) segundo a AOAC (2000) nº 981.12.

3.2.2 Medições da Força de Cisalhamento (FC)

A força de cisalhamento (FC) foi determinada na região cranial dos peitos crus que foram cortados em dimensões 10 x 10 x 30 mm (largura, altura e comprimento) com a maior dimensão paralela à direção da fibra, e analisados no Texturômetro TA-TX2i (texturometer Stable Micro Systems, Godalming, Surrey, UK) com célula de carga de 50 kg, equipado com lâmina Warner-Bratzler (HDP/WBV) e regulado com velocidades de descida e penetração de 100 $mm.min^{-1}$, profundidade de penetração de 20 mm e uma força de contato de 10 g. A força de cisalhamento foi expressa em Newton (N).

3.2.3 Cor Instrumental

A cor instrumental foi determinada através das leituras dos parâmetros L* (luminosidade), a* (intensidade de vermelho/verde) e b* (intensidade de amarelo/azul) utilizando um colorímetro digital Konica Minolta (Modelo CR-400, Osaka, Japão), na porção cranial e caudal na superfície dorsal (lado do osso) do peito de frango. As seguintes condições foram definidas para a leitura: iluminante C, ângulo de visão de 8°, ângulo padrão do observador de 10° especular incluído, conforme especificações da Commission Internationale de L'éclairage (CIE, 1986). Antes da realização das leituras, o instrumento foi calibrado em uma placa de cerâmica branca (Iluminante C: Y = 92,84 X = 0,3136, y = 0,3201).

3.2.4 Análises de oxidação lipídica e proteica

A oxidação lipídica foi determinada nos peitos crus e assados pelo ensaio de substâncias reativas ao ácido tiobarbitúrico (TBARS) de acordo com Rosmini et al. (1996). As absorbâncias da amostra foram medidas em espectrofotômetro a 532 nm. Os resultados foram expressos como mg MDA/kg amostra. Para cálculo da concentração de MDA foi usada uma curva padrão de 1,1,3,3 tetraetoxipropano.

O aroma requentado (WOF) foi determinado de acordo com Soares et al. (2004) com adaptações. As amostras foram assadas em forno convencional (temperatura interna à 75 ºC) e armazenadas a 4 °C por 48 h sob luz fluorescente. Em seguida, as amostras foram reaquecidas em banho-maria a 85 ºC por 15 min, posteriormente resfriadas e analisadas quanto ao teor de oxidação lipídica conforme metodologia descrita por Rosmini et al. (1996).

A oxidação de proteínas foi determinada em filés crus e assados pelo método da dinitrofenilhidrazina (DNPH) descrito por Ganhão et al. (2010). O resultado foi expresso em nmoles de carbonilas/ mg de proteína. Para cálculo da concentração de proteína foi usada uma curva padrão de albumina de soro bovino, nas concentrações de 167 a 1500 μg/mL.

3.2.5 Análise de compostos voláteis

O perfil de voláteis foi determinado nos peitos crus e assados (ver item 3.1.1). A extração dos voláteis foi realizada através da técnica de micro extração em fase sólida (SPME), segundo metodologia de Madruga et al. (2009) com adaptações. A fibra utilizada foi de 65 μm Polidimetilsiloxano/Divinilbenzeno (PDMS/DVB), ativada de acordo com as condições do fabricante (250 °C/30 minutos). Cerca de 2 g de cada amostra foi triturada (crua e cozida), onde posteriormente foi colocada em frascos de vidro de 20 mL hermeticamente fechados com tampa rosqueável, contendo septo revestido de teflon. Alíquota de 1,0 μl de um padrão interno (1000 ng μl 1,2-diclorobenzeno em metanol) foi adicionado a amostra, antes da coleta dos voláteis. Após atingir o equilíbrio (60 °C/5 minutos), a fibra foi exposta ao headspace por 60 minutos para extração. Após este tempo, o dispositivo SPME foi movido do frasco da amostra e inserido diretamente na porta de injeção do cromatógrafo gasoso 7890B acoplado ao espectrômetro de massas (Agilent Technologies 5977B, Little Falls, DE, USA), responsáveis por separar e identificar os voláteis coletados pela SPME. Foi utilizada a coluna VF-5MS (30 m x 25 mm x

0,25 μm). Foram utilizadas as seguintes condições analíticas no CG/EM: temperatura inicial do forno 40 °C/2 minutos, aumentando-se 4 °C min-1 até atingir 280 °C, permanecendo por 10 minutos, totalizando 72 minutos de corrida. A temperatura do injetor foi fixada em 250 °C. O hélio foi usado como gás de arraste na vazão de 1,0 mL/minuto no sistema de injeção split 1:10. A temperatura da linha de transferência foi de 170 °C. O espectrômetro de massas foi operado no modo impacto de elétrons (70 e V) e a faixa de "scanning" de massa foi de 35 a 350 u.m.a a 3,33 scans/s. A identificação dos compostos foi realizada pela análise dos padrões de fragmentação exibidos nos espectros de massas, sendo confirmada por comparação dos seus espectros de massas com aqueles presentes na base de dados fornecida pelo equipamento NIST (National Institute of Standards & Technology, E.U.A), bem como através dos seus índices de retenção linear com os de compostos conhecidos. As quantidades aproximadas dos voláteis foram estimadas por comparação de suas áreas de pico com a do padrão interno 1,2-diclorobenzeno, obtido a partir dos cromatogramas de íons totais, usando um fator de resposta 1. Os compostos voláteis foram agrupados em classes químicas, onde cada amostra foi injetada em triplicata.

3.2.6 Avaliação Sensorial

3.2.6.1 Análise Descritiva Quantitativa (ADQ)

O perfil sensorial (aroma) dos filés de frango WS foram caracterizados por um painel sensorial treinado, comparativamente ao perfil sensorial (aroma) de filés N.

3.2.6.2 Preparo dos filés

Um total de 10 g das amostras dos filés WS e N, foram servidos aos membros da equipe sensorial em um recipiente cilíndrico de vidro de 40 mL, transparente, inodoro, com tampa metálica e codificadas com números aleatórios de três dígitos. Cada amostra foi avaliada individualmente, juntamente com água (150 mL), para limpeza de olfato. As amostras foram apresentadas na forma de cubo (2 x 2 x 2 cm).

3.2.6.3 Seleção da equipe sensorial

No total 15 (quinze) voluntários foram recrutados entre estudantes e colaboradores do PPGCTA da Universidade Federal da Paraíba, Brasil, com idades entre 21 e 59 anos. Antes do início das avaliações, a equipe foi apresentada ao Termo de Consentimento Livre e Esclarecido (TCLE), previamente aprovado por o Comitê de Ética e Pesquisa com Seres Humanos da UFPB (CAAE 26383519.3.0000.5188 – APÊNDICE - A), atendendo as normas éticas e científicas requisitos da Resolução número 466, Nacional Conselho de Saúde (BRASIL, 2012).

3.2.6.4 Perfil sensorial dos filés

O perfil sensorial das amostras foi avaliado utilizando os fundamentos metodológicos da Análise Descritiva Quantitativa proposta por Stone et al. (1974). Sob a supervisão de um líder, os termos foram consensualmente escolhidos, definidos, criando-se para cada um referências associadas a cada termo. Uma ficha de avaliação descritiva foi consensualmente gerada (APÊNDICE - B), associando-se a cada termo, uma escala não estruturada de 10 cm, ancorada nos extremos esquerdo e direito nos termos “nenhum/fraco” e “forte”, respectivamente.

Sessões de treinamento foram conduzidas, nas quais os julgadores leram as definições de cada descritor, avaliaram as referências e, utilizando a ficha descritiva consensualmente desenvolvida e avaliaram as amostras de filés. A etapa de treinamento foi finalizada quando o líder da equipe observou que os julgadores conseguiam, através da ficha descritiva, discriminar amostras de filés de peito de frango.

Os julgadores avaliaram as amostras em três repetições e os resultados foram analisados estatisticamente por análise de variância univariada (ANOVA) com duas fontes de variação (amostra e repetição). Foram considerados os valores de significância (p-valor) do $F_{amostra}$ e do $F_{repetição}$ para cada julgador em cada descritor, e selecionados os indivíduos com $pF_{amostra} < 0,30$, $pF_{repetição} > 0,05$ e consenso com os demais julgadores da equipe para pelo menos 80% dos descritores. Sendo assim, foram selecionados um total de doze (12) julgadores. As três amostras foram avaliadas em triplicata em diferentes sessões, balanceando-se a ordem de apresentação das mesmas entre os julgadores e repetições.

3.3 ANÁLISE ESTATÍSTICA

Foi realizado o teste de normalidade Shapiro-Wilk ($\alpha = 0,05$). Nos resultados das análises físico-químicas, para comparar duas amostras (N e WS), foi utilizado o teste paramétrico de t-student ($p<0,05$). Para comparar cada amostra ao longo do armazenamento, seja refrigerado (tempos 0, 11 e 14 dias) e congelado (tempos 0, 45 e 90 dias) foi aplicada ANOVA e as médias foram comparadas pelo teste de Tukey ($p<0,05$). As respostas sensoriais foram analisadas por meio de análise de variância univariada (ANOVA) para avaliar o efeito da amostra com teste de média Tukey ($p<0,05$), e t-test (two-tailed) para a avaliação do efeito do tempo de armazenamento ($p<0,05$). Os resultados da sensorial e dos compostos voláteis foram auto-escalonados usando o software MATLAB (The Mathworks, Inc., versão 7.10.0.499, Natick, MA, R2010a) para a comparação das concentrações dos voláteis e dos resultados da sensorial para cada amostra, e após tratamento os dados foram submetidos a Análise de Componentes Principais (ACP). Os dados foram analisados utilizando o software XLSTAT (versão 2014.5.03, Addinsoft, New York, USA), e os gráficos foram gerados no Software GraphPad Prism versão 6 (GraphPad Software Inc.).

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5. RESULTADOS E DISCUSSÃO

Os resultados obtidos nesta pesquisa estão apresentados no formato de artigo, em atendimento a Norma Complementar nº 03/2011 do PPGCTA. O formato dos artigos está de acordo com os periódicos *Poultry Science* e LWT, respectivamente.

ARTIGO 1 - QUALIDADE OXIDATIVA DE FILÉS DE FRANGO WS QUANDO SUBMETIDOS À REFRIGERAÇÃO E AO CONGELAMENTO

ARTIGO 2 - EFEITO DO ARMAZENAMENTO REFRIGERADO E CONGELADO NO PERFIL SENSORIAL E DE VOLÁTEIS DE FILÉS DE PEITO DE FRANGO ESTRIADO (WS) E NORMAL

1 5.1 ARTIGO 1: OXIDATIVE QUALITY AND WHITE STRIPING FILLETS

2

3 **OXIDATIVE QUALITY AND WHITE STRIPING FILLETS**

4

5 **Oxidative quality of white striping broiler breast fillets stored under refrigeration**
6 **and freezing conditions**

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ABSTRACT

This study aimed to investigate the effect of refrigeration (1 °C for 14 days) and freezing (-18 ºC for 90 days) storage conditions on the meat quality of broiler breast fillets with severe white striping (**WS**), evaluating the role of lipid and protein oxidation in the loss of broiler meat quality. The severe white striping (WS; striation thickness > 1 mm) presented higher lipid content, although no difference in protein content was detected, compared to normal broiler breast (**N**). Refrigerated storage resulted in lower pH and influenced the shear force and color parameters. Regarding oxidative damages, a reduction in malondialdehyde (**MDA**) and carbonyl levels, alongside the interaction of these compounds with other compounds in raw, roasted, and reheated fillets was observed under refrigerated storage (14 days). The freezing condition significantly reduced the pH, shear force, and yellowness (b*) of WS and N fillets without altering the moisture content and maintaining the oxidative levels of WS fillets in an MDA range that leads to the formation of unpleasant flavors and odors, which may be noticeable by consumers. The higher level of carbonyls in WS fillets compared to N fillets negatively impacts the quality of the product (loss of essential amino acids) and its digestibility. Therefore, refrigerated storage (up to 11 days) is recommended for WS broiler fillets, preserving the fillets' quality until consumption.

Keywords: storage, myopathy, oxidative damage, *White Striping*.

INTRODUCTION

The world broiler meat production between 2000 and 2020 increased by 104%, from 58.6 million to 119.5 million tons, respectively. Brazilian production increased 2.3 times in the same period, from 6 million to 14 million tons, accounting for ~11.5% of

world production in 2020 (Faostat, 2021). In this context, Brazil has been highlighted as one of the largest world producers and exporters of broiler meat (ABPA, 2020).

The increase in production and consumption of broiler meat was made possible due to the advances in broiler genetic selection and animal feed programs. However, these advances are associated with the occurrence of myopathies in broiler chickens (Mudalal et al., 2015). Amongst them, white striping (**WS**) myopathy is easily recognized by the occurrence of white striations on the surface of the breast, which may lead to a product rejection by the consumers (Carvalho et al., 2021a; Pereira et al., 2022).

The effects of WS are noticeable in the breast muscle (*Pectoralis major* - **PM**) by altering histopathological conditions when the breasts are affected mainly by severe myopathy, which leads to the installation of necrosis, lysis of fibers, infiltration of inflammatory cells, gradual replacement of muscles by connective tissue (fibrosis) and deposition of adipose tissue. Additionally, the nutritional and technological value of WS meat decreases compared to normal meats (Kuttappan et al., 2012; Soglia et al., 2016; Baldi et al., 2018).

In the literature, there are few studies that compare the quality of broiler breasts affected by WS myopathy during storage under different conditions (refrigeration or freezing). Beltrán and Bellés (2019) reported that the storage of raw broiler meat under refrigeration or freezing temperatures could be considered one of the best conservation techniques since the cold chain is respected. Ali et al. (2015), investigating several cycles of freezing and thawing on the quality of broiler breasts, identified an increased lipid and protein oxidation, alongside reduced color stability and pH.

Therefore, this study is aimed to investigate the physicochemical quality and oxidation levels of lipids and proteins in broiler breasts affected by WS when stored under refrigeration and freezing conditions.

MATERIALS AND METHODS

Selection of Broiler Breasts

Broiler breasts (Cobb®) were collected in a commercial slaughterhouse (Pernambuco, Brazil) under Brazil's Federal Inspection Service regulations. After slaughter and deboning, the broiler breast fillets (*Pectoralis major* muscle) were selected and classified into Severe White Striping (WS; striation thickness > 1 mm) and Normal (**N**; absence of white striping) based on the visual appearance of the muscle. A total of 30 breast fillets (15 N fillets and 15 WS fillets) were selected. After classification, the fillets were individually packed in Zip Lock bags and taken to the laboratory under refrigeration (< 4 ºC).

Following that, the excess fat, bone fragments, and connective tissue were removed from the broiler breasts, and the fillets were analyzed on day 0 (3 N and 3 WS). The remaining broiler breasts (12 N and 12 WS) were stored under refrigeration (1 °C) for 11 and 14 days or under freezing (-18 ºC) for 45 and 90 days. Once achieved the storage period for each temperature condition, 3 N and 3 WS broiler breasts were collected, and the breast fillets were analyzed for their physicochemical characteristics and protein and lipid oxidation.

Physicochemical Characterization

The chemical composition was determined in the WS and N breast fillets according to AOAC methods for moisture content (no. 950.46.41) and proteins (no. 928.08) (AOAC, 2000). Lipid content was evaluated according to Folch et al. (1957). The pH was determined using a pH meter Model Q400 AS (Quimis Aparelhos Científicos Ltda., Diadema, Brazil) according to method no. 981.12 (AOAC, 2000). The protein and

lipid contents were only analyzed on day 0; the other parameters were measured throughout storage.

The color was measured at two points of the breast muscle's dorsal surface (inner surface and side of the bone), in the cranial and caudal regions, using the Konica Minolta colorimeter (Chroma Meter CR-400, Minolta Co., Osaka, Japan). Shear force (**SF**) was determined in the cranial region of raw breast muscles, cut in pieces of 10 x 10 x 30 mm (width, height, and length) with the length parallel to the direction of the fiber. The SF was measured using a Texturometer TA-TXplus (Stable Micro Systems, Godalming, Surrey, UK) with a load cell of 50 kg, equipped with a Warner-Bratzler blade (HDP/WBV) and regulated with a crosshead speed of 100 $mm \cdot min^{-1}$, the penetration depth of 20 mm and a contact force of 10 g. Shear force was expressed in Newton (N).

Oxidative Damages

Lipid oxidation was carried out through the spectrophotometric measurement of thiobarbituric acid reactive substances (TBARS) at 532 nm, according to Rosmini et al. (1996), in WS and N fillets (raw and roasted); where the roasted fillets were prepared in an oven (180ºC) until they reached the internal temperature of 75 ºC. To quantify the malondialdehyde (**MDA**) content, a standard curve of 1,1,3,3-tetramethoxypropane (ranging from $2x10^{-9}$ to $6x10^{-8}$ mol) was used. The results were expressed as mg of $MDA \cdot kg^{-1}$ of meat. The warmed-over flavor (WOF) of WS and N fillets was determined as described by Soares et al. (2004), with modifications. WS and N fillets were roasted and stored at 4 °C for 48 h under fluorescent light. Then, they were warmed in a water bath at 85 ºC for 15 min, cooled at room temperature, and analyzed for lipid oxidation (Rosmini et al., 1996). Protein oxidation was measured according to the dinitrophenylhydrazine (DNPH) method described by Ganhão et al. (2010). A standard

bovine serum albumin curve (ranging from 167 to 1500 $\mu g \cdot mL^{-1}$) was used to calculate protein concentration. Protein oxidation was expressed in nmoles of carbonyls$\cdot mg^{-1}$ of proteins.

Statistical Analysis

The Shapiro-Wilk test was used for testing the normality ($\alpha = 0.05$). WS and N mean values were compared using Student's t-test ($P < 0.05$). A one-way ANOVA was carried out to evaluate the changes during storage, and post-hoc Tukey's test ($P < 0.05$) was applied to compare the means. Data were analyzed using XLSTAT (version 2014.5.03, Addinsoft, New York, USA).

RESULTS AND DISCUSSION

Physicochemical Characterization of WS and N Fillets

The WS fillets presented a lipid content of 2.20 $g.100^{-1}$, which was 1.5x higher than that of N fillets (1.48 $g.100^{-1}$). According to Petracci et al. (2019), the accumulation of lipids in the *Pectoralis major* muscle affected by white striping causes important modifications; this phenomenon is called lipidosis. The protein content of WS fillets (21.31 $g \cdot 100^{-1}$) was similar to that of N fillets (21.69 $g \cdot 100^{-1}$).

There was no significant difference ($P > 0.05$) in the moisture content between WS and N fillets over the refrigerated (Fig. 1A) and frozen (Fig. 1B) storage period. Furthermore, the moisture content for WS and N samples did not vary along the storage period, regardless of the preservation condition applied. The moisture content of WS and N broiler fillets ranged from 70.59 to 76.2%, matching the values observed in the literature (Kuttappan et al., 2012; Petracci et al., 2014; Soglia et al., 2016, 2018; Baldi et

al., 2018; Giampietro-Ganeco et al., 2021); this indicates that myopathy and the storage conditions applied had no influence on moisture content in broiler breast fillets.

During the refrigerated storage, the WS and N breast fillets showed a significant decrease ($P < 0.05$) in the pH values after 14 days, with changes ranging from 5.90 to 5.38 and from 5.95 to 5.31 in WS and N meats, respectively (Fig. 1C). According to Carvalho et al. (2020), this fact may be related to post-mortem biochemical processes with the decrease in glycogen content and increased acidification, affecting the tenderness of the meat. Petracci et al. (2019) stated that a low final pH (close to the isoelectric point of muscle proteins, approximately 5.0) leads to muscles with low water-holding capacity (**WHC**), while muscles with higher final pH present high WHC. Moreover, pH values close to the isoelectric point of muscle proteins result in water losses from muscles due to the shrinking of myofibrils, leading to a higher lightness index caused by increased light dispersion on the meat surface (Monin and Santé-Lhoutellier, 2014).

The pH of broiler chicken breast is also correlated with its preservation since values lower than 5.5 inhibit or prevent microbial growth. This pH range indicates acidification due to increased lactic acid/lactate formation, providing a desirable flavor component of the broiler meat and increasing the meat tenderness, which is an essential parameter for *rigor-mortis* (Honikel, 2014).

In this study, the WS and N broiler fillets did not differ ($P > 0.05$) in relation to pH in any of the storage times that have been evaluated. There is no unanimity on the difference in pH between white striping and normal broiler chicken breasts in the literature. Alnahhas et al. (2016) observed that, regardless of the degree of white striping, the pH of the broiler breast did not present a significant difference compared to normal broiler breast. This result differed from Petracci et al. (2013), who observed that the pH

of broiler breasts affected by white striping disorder is usually several decimal cases (from 0.2 to 0.4) higher than normal ones.

A different behavior was observed under freezing storage conditions (Fig. 1D), i.e., there was a significant reduction in pH for WS and N fillets after 45 days of storage, followed by an increase up to the initial pH value after 90 days. This pH change within 45 days may be related to that described by Sylvestre et al. (2001), who reported that meat freezing leads to protein denaturation reactions, thus producing free peptides and amino acids, which influence the final pH of the meat. However, it is essential to note that WS and N broiler fillets under freezing showed similar pH during the storage period; there was no difference ($P > 0.05$) between the samples.

The shear force for WS and N fillets showed no significant difference ($P > 0.05$) between each other during refrigerated storage (Fig. 1E). Studies have reported that the texture properties of broiler breasts are not overly influenced by the presence of white striping myopathy (Tasoniero et al., 2016; Baldi et al., 2018; Petracci et al., 2019). In addition, some authors found non-significant effects of the WS disorder on broiler meat texture (Kuttappan et al., 2012). On the other hand, several studies reported significant differences only when the most severe degrees of white striping were evaluated (Brambila et al., 2016; Giampietro-Ganego et al., 2021; Petracci et al., 2013).

A decrease in SF was observed for both WS and N fillets after 14 days under refrigerated storage (Fig. 1E). Furthermore, a relationship between the pH reduction and the water-holding capacity can be suggested in the same period. Muscles with low water-holding capacity lead to lower SF values since the water makes muscle cells support greater forces (Petracci et al., 2014).

No significant differences ($P > 0.05$) for shear force were observed between WS and N broiler fillets, regardless of the storage condition applied (Fig. 1E and 1F). Under

192 frozen storage, a significant reduction in SF was observed after 45 days of storage for
193 both WS and N meats; then stability was noticed up to 90 days. According to Leygonie
194 et al. (2012), this effect may be due to the water loss during thawing, with denaturation
195 of sarcoplasmic proteins as a consequence of slow freezing, which causes the formation
196 of large ice crystals in the extracellular medium, decreasing the myofilament spacing and
197 leading to water exudation, hence increasing the concentration of free water and
198 decreasing the water-holding capacity alongside shear force. Furthermore, the water loss
199 is also caused by intracellular damage due to the ice crystals formation.

200 Regarding the color parameters in the cranial region of the breasts stored under
201 refrigeration (Fig. 2), WS broiler breasts showed higher values ($P < 0.05$) for color
202 coordinate a* and lower values ($P < 0.05$) for color coordinate b* during refrigerated
203 storage, i.e., higher intensity of red (a*) on the 11th day, and lower intensity of yellow
204 (b*) on day 0 and after 14 days of storage, when compared to N broiler breasts (Fig. 2B
205 and 2C). No significant difference ($P > 0.05$) was observed in the lightness (L*) in the
206 cranial region of the breasts, either during storage or between samples (Fig. 2A). In
207 studies comparing white striping and normal breasts, Alnahhas et al. (2016) found higher
208 L* in WS fillets than in normal fillets. Kuttappan and Brewer (2010), Petracci et al.
209 (2013), Trocino et al. (2015), and Giampietro-Ganeco et al. (2021), although not use L*
210 as a discriminating factor to assess the presence of white striping, reported increased
211 redness (a*) in WS fillets compared to normal fillets. When analyzing the breasts' caudal
212 region (Fig. 2D and E), a significant difference for the parameters L* and a* was observed
213 between WS and N fillets after 11 days of refrigerated storage, whereas the yellowness
214 (b*) presented a significant difference on day 0 (Fig. 2F).

215 The influence of freezing on the color of WS broiler breasts was evaluated, and
216 the lightness (L*) in the cranial region showed a significant decrease ($P < 0.05$) after 45

days of storage (Fig. 3A). The reduction in L* after 45 days of freezing is possibly due to the denaturation of proteins during thawing, as was reported by Soglia et al. (2019), who observed a reduction in L* after freezing and subsequent thawing of meat affected by myopathy. This effect can be attributed to the change in meat structure resulting from the production of ice crystals during frozen storage and may predominantly affect the structure of WS muscles (Soglia et al., 2016), resulting in an altered muscle structure that leads to a different scattering of the incident light. The lightness (L*) in the caudal region (Fig 3 D) and redness (a*) in the cranial and caudal regions (Fig. 3B and 3E, respectively) did not present significant differences ($P > 0.05$) between WS and N samples throughout the storage period. While yellowness (b*) showed differences between samples only on day 0, in both cranial and caudal regions of the broiler breasts.

Oxidative Damages

Lipid oxidation levels decreased in WS raw (Fig. 4A), roasted (Fig.4B), and reheated (Fig.4C) fillets under refrigerated storage. For N fillets, a slight increase was observed after 14 days for raw fillets, and a reduction after 11 days was noticed for roasted fillets. In the refrigerated storage period, a reduction in malondialdehyde formation was observed in the first 11 days, from 0.45 to 0.1 mg MDA·kg^{-1} for WS raw fillets and from 4.3 to ~0 mg MDA·kg^{-1} for WS roasted fillets. For the reheated WS fillets, the lipid oxidation reduction occurred after 14 days, reaching levels close to 1.8 mg MDA·kg^{-1}. It was possible to observe differences in lipid oxidation between the WS and N fillets, regardless of the preparation condition (raw, roasted, or reheated). It is worth mentioning that on day 0, the WS samples presented a higher level of lipid oxidation compared to N breast fillets. The differences between WS and N corroborate the findings of Baldi et al. (2018), who reported higher initial levels of MDA for WS fillets compared to N fillets.

242 However, on day 14 for raw fillets and days 11 and 14 for roasted fillets, this effect was
243 contrary, in which WS presented a lower level of lipid oxidation (Fig.4 A and B)
244 compared to N.

245 During the refrigerated storage, WS raw and roasted samples, except on day 0,
246 presented values for lipid oxidation below 0.5 mg MDA·kg^{-1}. According to Wood et al.
247 (2008), values above that are considered critical since they indicate a high level of lipid
248 oxidation, producing a rancid flavor. Other authors also reported that TBARS values
249 between 1 and 2 mg MDA·kg^{-1} are in the sensory detected range (Wood et al., 2008; Baldi
250 et al., 2020; Carvalho et al., 2021a.; Pereira et al., 2022).

251 According to Papastergiadis et al. (2012), the reduction of malondialdehyde
252 formation during storage may be associated with the occurrence of other reactions among
253 secondary lipid oxidation products or the formation of other oxidation products that have
254 not been detected (other than MDA compound) as well as the reaction of MDA with other
255 compounds. Salles et al. (2019) observed higher lipid oxidation in fillets affected by
256 severe white striping disorder. In addition, they verified higher protein oxidation and the
257 formation of free radicals in fillets with moderate to severe myopathy. Leite et al. (2020)
258 observed in WS fillets an increase in susceptibility to lipid oxidation after cooking,
259 detected from the increase in the warmed-over flavor and suggested that this increase may
260 occur due to the higher content of polyunsaturated fatty acids, compromising its quality
261 due to the formation of unpleasant odors detected by consumers.

262 Regarding carbonylation level, WS fillets only presented differences in protein
263 oxidation compared to N fillets on day 0 for raw breast fillets (higher level compared to
264 N) and on day 14 for roasted breast fillets (lower level compared to N). Higher protein
265 oxidation levels in WS meat were also observed by Carvalho et al. (2021a), who reported
266 an increase in the concentrations of allysine and Schiff base, which are protein oxidation

products. Evaluating the effect of storage under refrigeration on WS and N fillets, significant differences were observed between the roasted samples on days 0, 11, and 14. Regarding carbonylation level for raw fillets, no abrupt changes occurred as it was observed for roasted fillets from day 0 to day 11, showing a high decreasing rate varying from 11.0 to approximately 3.00 $nmol \cdot mg^{-1}$ protein for both WS and N fillets.

Considering the pH decline for WS and N meats throughout storage, as pointed out in this study (Fig. 1C), this may have influenced the increased extent of carbonylation. As described by Estévez et al. (2019), the decline of pH during muscle conversion into meat results in aggregation, denaturation, and decreased solubility of muscle proteins, favoring the oxidation process; in addition, high concentrations of H^+ may favor the redox cycle of myoglobin and, consequently, its pro-oxidant potential. Estévez et al. (2011) reported various chemical changes suffered by proteins during the storage of chicken meat products, including carbonylation, carboxylation, and cross-linking.

According to the oxidation data observed and those described in the literature, it was found that lipid and protein oxidation is closely associated with deterioration processes that can affect all quality characteristics of meat and meat products. Moreover, a correlation between the levels of oxidative indicators for lipids (TBARS) and those for proteins (carbonyl groups) was observed. This fact can be noticed when comparing the data for oxidative rancidity and protein denaturation of WS fillets after 11 days of refrigerated storage, showing a simultaneous reduction in MDA and carbonyls levels (Ganhão et al., 2010; Ferreira et al., 2016; Cavalcante da Rocha et al., 2020; Carvalho et al., 2021b).

During the storage period under freezing, the levels of lipid oxidation in WS raw (Fig. 5A), roasted (Fig.5B), and reheated (Fig.5C) samples showed a significant reduction after 45 days. In this storage period, a downward slope for malondialdehyde formation

292 was observed, decreasing from 0.45 to 0.18 mg MDA·kg^{-1} for WS raw fillets; from 3.4
293 to 2.5 mg MDA·kg^{-1} for WS roasted fillets, and from 3.0 to 2.5 mg MDA·kg^{-1} for WS
294 reheated fillets.

295 WS raw fillets (Fig. 5D) obtained significantly higher levels of protein carbonyls
296 compared to N raw fillets ($P < 0.05$) on days 0 and 90. While evaluating the level of
297 carbonylation in the roasted samples (Fig. 5E), it was observed that there were significant
298 differences ($P < 0.05$) between WS and N samples after 45 days, where N samples
299 presented higher levels compared to WS. In addition, it was observed that freezing had
300 an effect on both WS and N broiler breast fillets after 45 days, reducing carbonyl levels
301 and hence protein oxidation.

302 However, higher MDA levels were observed in WS and N breast fillets stored
303 under refrigeration for both roasted and reheated fillets, ranging between 3.5 and 2.0 mg
304 MDA·kg^{-1}, which is an indication that the samples affected by the WS myopathy, when
305 submitted to heat treatment, are more susceptible to lipid oxidation. Additionally, it can
306 be assumed that freezing did not have the same preservation effect when compared to
307 refrigeration; and this result can be associated with disruption of muscle cells caused by
308 ice crystals that may have exposed the intracellular material, which contributes to
309 oxidative reactions (Ganhão et al., 2010; Leygonie et al., 2012; Leite et al., 2020;
310 Carvalho et al., 2021). Therefore, these above-mentioned results explain the warmed-over
311 flavor characteristic of poultry meat, which can cause rejection by the consumer and
312 significant economic losses to the meat industry (Wood et al., 2008; Ferreira et al., 2016;
313 Rocha et al., 2020; Lee et al., 2021).

314

315 **CONCLUSION**

316 WS breast fillets showed lipid content higher than N breast fillets, although no

difference in protein content was detected. Storage under refrigeration resulted in a significant reduction in pH and changes in shear force and color parameters, especially the redness (a*) and yellowness (b*) of WS breasts. The analysis of oxidative damage revealed a reduction in the levels of malondialdehyde and carbonyls, possibly interconnected, and the interaction of these compounds with other compounds of raw, roasted, and reheated fillets when refrigerated for 14 days.

Freezing storage significantly reduced the pH, shear force, and yellowness (b*) of WS and N fillets without altering moisture content. It is significant to note that freezing is a storage condition that leads to higher lipid and protein oxidation levels than refrigeration, especially for roasted and reheated meats affected by white striping disorder. Therefore, we recommend the refrigerated storage for 11 days as the preservation technique to be employed in WS broiler breast fillets to preserve the quality of the product.

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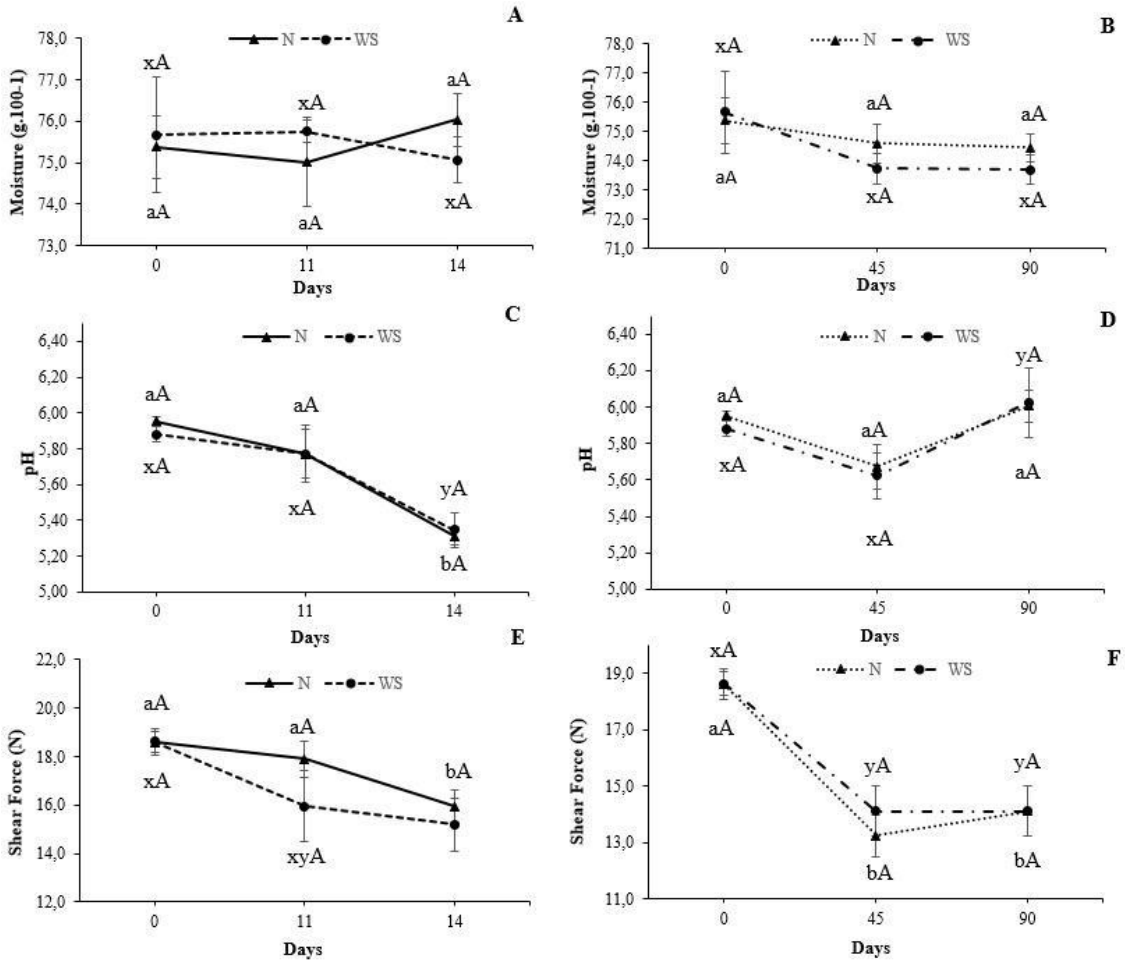
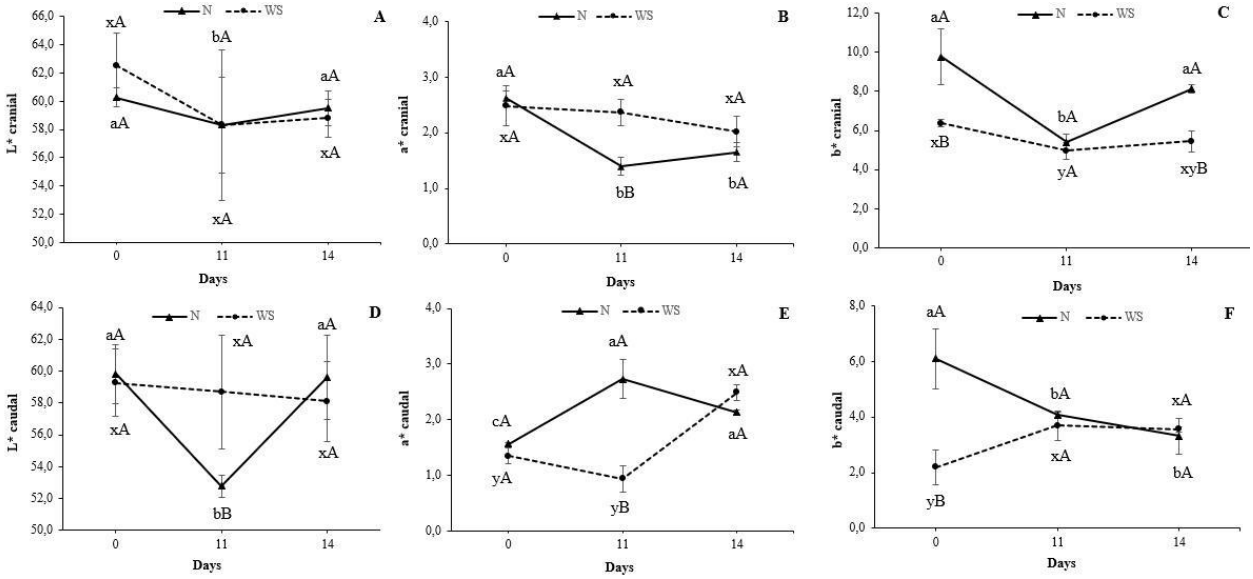
FIGURES

Figure 1 – Changes in moisture content (A, B), pH (C, D), and shear force (E, F) of WS and N broiler breasts during cold storage (refrigeration and freezing, respectively).



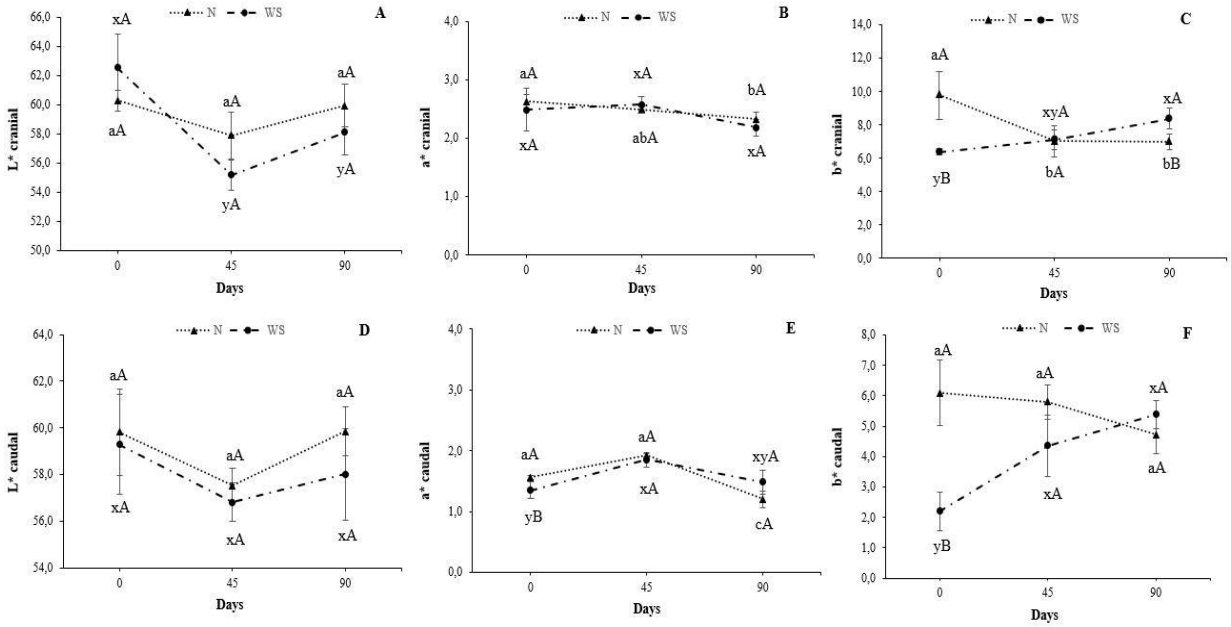
Different lowercase letters (a, b, and c) in **—N—** indicate significant differences over storage time. Different lowercase letters (x, y, and z) in **---WS---** indicate significant differences over storage time. Different uppercase letters (A and B) indicate significant differences between N and WS over the storage time.

Figure 2 – Evolution of instrumental lightness (L*), redness (a*), and yellowness (b*) in the cranial (A, B, C) and caudal (D, E, F) regions of WS and N broiler breasts during refrigerated storage.



Different lowercase letters (a, b, and c) in **—N—** indicate significant differences over storage time. Different lowercase letters (x, y, and z) in **---WS---** indicate significant differences over storage time. Different uppercase letters (A and B) indicate significant differences between N and WS over the storage time.

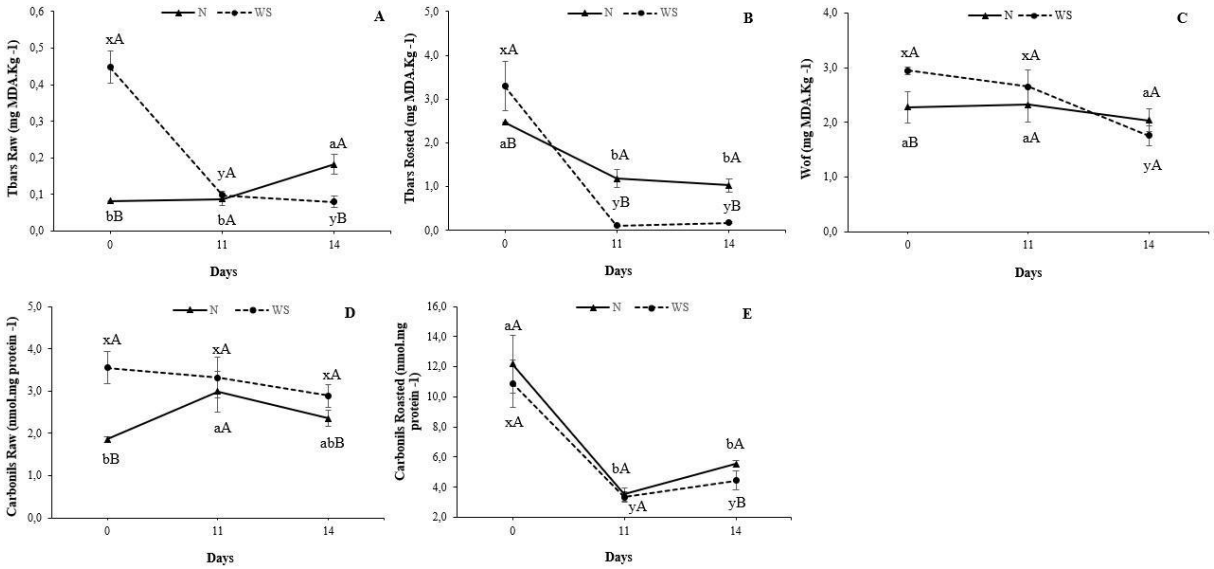
Figure 3 – Evolution of instrumental lightness (L*), redness (a*), and yellowness (b*) in the cranial (A, B, C) and caudal (D, E, F) regions of WS and N broiler breasts during frozen storage.



Different lowercase letters (a, b, and c) in **—N—** indicate significant differences over storage time. Different lowercase letters (x, y, and z) in **---WS---** indicate significant differences over storage time. Different uppercase letters (A and B) indicate significant differences between N and WS over the storage time.

480 **Figure 4 –** Evolution of lipid (A, B, C) and protein (D, E) oxidation of WS and N broiler breasts
481 during refrigerated storage.

482

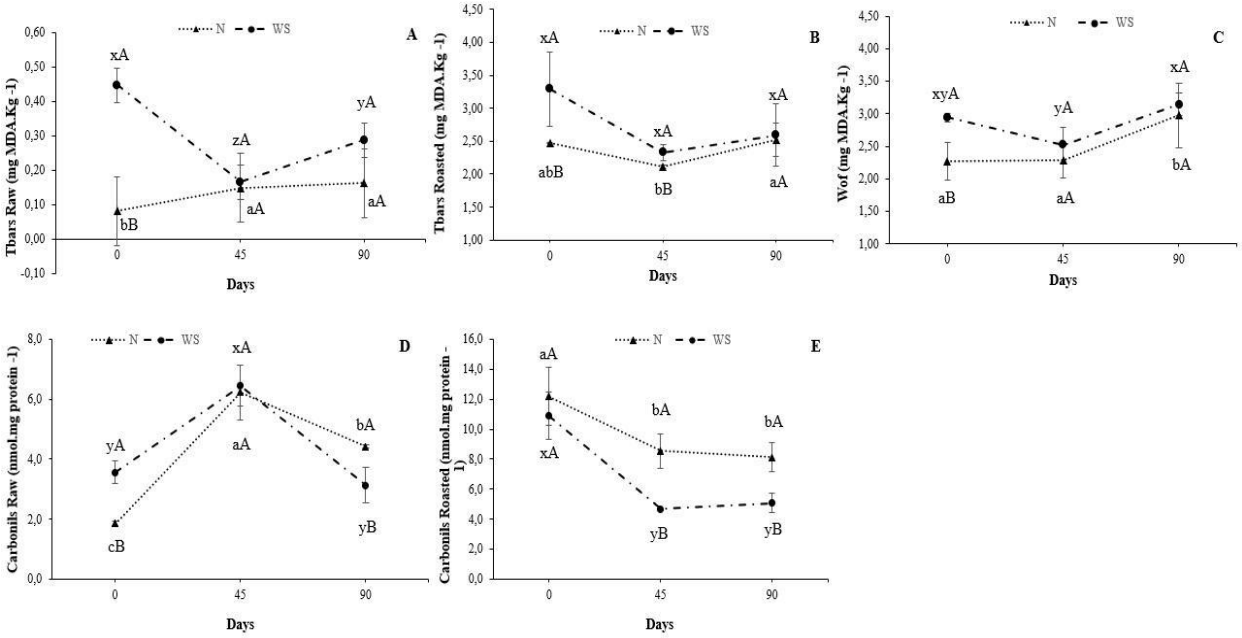


483
484

485 Different lowercase letters (a, b, and c) in **—N—** indicate significant differences over storage time. Different
486 lowercase letters (x, y, and z) in **---WS---** indicate significant differences over storage time. Different uppercase
487 letters (A and B) indicate significant differences between N and WS over the storage time.

488

Figure 5 – Evolution of lipid (A, B, C) and protein (D, E) oxidation of WS and N broiler breasts during frozen storage.



Different lowercase letters (a, b, and c) in **—N—** indicate significant differences over storage time. Different lowercase letters (x, y, and z) in **---WS---** indicate significant differences over storage time. Different uppercase letters (A and B) indicate significant differences between N and WS over the storage time.

5.2 ARTIGO 2: EFFECT OF REFRIGERATION AND FREEZING ON THE SENSORY PROFILE AND VOLATILE COMPOUNDS OF WHITE STRIPING CHICKEN BREAST

Effect of refrigeration and freezing on the sensory profile and volatile compounds of white striping chicken breast

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Declarations of interest: none

Abbreviations: White striping myopathy (WS); Normal breast (N); Headspace Solid-Phase Micro-Extraction technique (HS-SPME); Divinylbenzene/Carboxen/Polydimethylsiloxane

(DVB/CAR/PDMS); Quantitative Descriptive Analysis (QDA); Analysis of variance (ANOVA); Principal Component Analysis (PCA).

Abstract

This study aimed to investigate the chemical and sensory aromatic quality of broiler breast with severe *White Striping* ([WS], white stripes >1 mm thickness) disorder when refrigerated and frozen. The number and concentration of volatile compounds in cold storage were higher in raw WS compared to raw normal (N) meat. The primary volatile compounds found were aldehydes, regardless of breast type and temperature storage condition. The number and concentration of volatile compounds in raw and roasted WS were higher when compared to N breasts at the beginning of the storage period (t=0 days). Throughout frozen storage, panellists noted the appearance of "sweet" and "rancid" aroma and a decrease in "metallic" aroma in raw WS breast. While the roasted WS breasts showed an increase in "sweet" aroma, and the appearance of "rancid" aromas, and "fish". The aromatic profile of raw and roasted broiler breasts is influenced not only by the occurrence of myopathy (WS) but also by the type of storage (refrigerated or frozen).

Keywords: aroma; cold storage; poultry; myopathies; shelf-life

1. Introduction

In 2021, 99.9 million tons of raw broiler chicken were produced, and Brazil contributed approximately 14.3 million tons of this, ranking as the 3rd largest producer and largest global exporter of broiler meat, exporting ~33% of its national production (ABPA, 2022).

From 2001 to 2021, the per capita consumption of broiler meat in Brazil increased from 31.8 to 45.6 kg/inhabitant/year (ABPA, 2013; 2022). Following this consumption and production growth, the poultry meat industry faced several abnormalities in broiler meat due to pre-

slaughter and post-slaughter factors (Kuttappan, Hargis, & Owens, 2016). Some abnormalities are specific to poultry meat. A major contributor is myopathy of the *pectoralis major* muscle of chicken, commonly termed as 'striated breast' or '*White Striping'* (WS). This alters the visual appearance of the breast and also modifies the chemical composition and technological characteristics of chicken meat (Petracci et al., 2019; Carvalho et al., 2021).

One of the main requirements in consumers' choice of meat and meat products is appearance. Some authors have reported that consumers use sensory parameters as a determinant factor in their decision to purchase (O'Sullivan, 2017; Lee et al., 2021). Appearance, colour, aroma, flavour and texture are connected to the overall acceptance and quality of meat, as these parameters are directly associated with the nutritional and functional properties of broiler meat (Min & Ahn, 2012).

Compared to the meat of other species, poultry meat is characterized by a higher content of unsaturated fatty acids that are susceptible to oxidation. Furthermore, due to the presence of deteriorating microorganisms, most commercialized chicken meat is stored under cooling or freezing. This extends the shelf-life by reducing the growth rates of microorganisms, chemical reactions and enzymatic activity (Al-Jasser, 2012; Stonehouse & Evans, 2015). Traditional refrigeration storage temperatures are usually between 0 °C and 7 °C (Xu et al., 2012; Latou et al., 2014); while in freeze storage, temperatures are < -18 °C. Although freezing is a well-known and widely used practice for meat preservation, its effect on meat quality remains a problem due to the complex physical, chemical and biochemical changes that may occur (Liu, Lin, & Chen, 2001; Soglia, Mazzoni, & Petracci, 2019).

Several studies have been conducted focusing on the impact of the refrigeration and freezing processes on the quality of broiler meat (Augustynska-Prejsnar et al., 2018; Augustynska-Prejsnar, Ormian, & Tobiasz-Salach, 2019; Wei et al., 2017). The results have indicated

increased moisture loss and oxidation of lipids and proteins, protein denaturation and undesirable colour changes as a result of freezing broiler meat (Wei et al., 2017).

Water-soluble components (proteins, amino acids, thiamine, sugars, etc.) and lipids are classified as aroma precursors in cooked meat. Water soluble components confer the characteristic flavours of the meat via the Maillard Reaction, in addition to the aromas generated from lipid oxidation (Mottram, 1998).

The understanding of the mechanisms involved in *pectoralis major* muscle changes of broilers affected by WS myopathy is well established (Kuttappan, Hargis, & Owens, 2016); however, there is still few data in the literature concerning the aromatic and sensory quality of WS breasts stored under colling or freezing conditions (Dalgaard et al., 2018; Gratta et al., 2019; Soglia, Mazzoni, Puolanne, & Cavani, 2017).

This study aimed to evaluate the influence of temperature storage (refrigeration or freezing) and *White Stripping* myopathy on the aromatic quality of raw and roasted broiler breasts. To achieve this, we analysed the volatile chemical and sensory profiles.

2. Materials and methods

2.1. Selection of Broiler Breasts

Broilers (males and females) of the Cobb® lineage were slaughtered at 42-46 days old in a commercial slaughterhouse in accordance with Brazil's Federal Inspection Service regulations (Brasil, 1998).

Broiler breasts (*Pectoralis major* muscle) were selected and classified into Severe *White Striping* (**WS**; striation thickness > 1 mm) and Normal (**N**; did not show white striation on breast surface) based on the visual appearance of the muscle. Thereafter, the broiler breasts were individually packed in ziplock bags and stored under refrigeration (1 ºC) for 0, 11 and 14

days, or freezing (-18 ºC) for 0, 45 and 90 days. The day 0 is equivalent to the sample analyzed 6 hours post-mortem (sample temperature ≤ 4ºC), moments before they were submitted to the storage procedure (refrigeration or frozen). The type of freezing used was slow (24 hours at -18ºC). Storage times (11 and 14 days for refrigeration) were chosen considering the shelf life for refrigerated chicken breast adopted by different slaughterhouses in Brazil. While the time of 90 days for freezing was chosen considering the average time between production and consumption of the product, although the shelf life of the product is up to 365 days.

A total of 30 breasts (15 N and 15 WB) were selected. For each timepoint of refrigerated storage (t = 0, 11 and 14 days) and frozen storage (t = 0, 45, 90), 3 WS breasts and 3 N breasts were collected and analysed. The experiment was repeated three times.

2.2. Volatile Profile

Volatile compound extraction was performed using the Headspace Solid-Phase Micro-Extraction technique (HS-SPME) for raw and roasted WS and N broiler breast samples stored under refrigeration or freezing conditions.

A 2 g sample of ground chicken meat was weighed into a 20 mL flask. A 1.0 µL aliquot of the internal standard 1,2-dichlorobenzene in methanol (50 $\mu g \cdot mL^{-1}$) was added to the sample before the collection of volatile compounds. An SPME fibre (50/30µm Divinylbenzene/Carboxen/Polydimethylsiloxane - DVB/CAR/PDMS) was inserted through the septum and left exposed in the upper space of the flask. The SPME fibre was preconditioned for analysis at 270 ºC for 60 min. The sample remained in equilibrium at 60 ºC for 5 min and volatile compounds extraction was performed at 60 ºC for 60 min. After extraction, the SPME fibre was immediately transferred to a 7890B gas chromatograph injector coupled to a mass spectrometer (Agilent Technologies 5977B, Little Falls, DE, USA), for separation and identification of the volatile compounds.

The separation was carried out using a VF-5MS capillary column (30 m×0.25 mm×0.25 μm) and the following GC/MS analytical conditions were used: initial oven temperature of 40 ºC for 2 min, then increased to 250 °C at 4 ºC·min^{-1}, remaining at 250 °C for 10 min, totalling 64.5 min of running time. The injector temperature was set at 250 °C and the GC was operated in the *split-less* mode. Helium was used as make-up gas at a flow rate of 1.0 mL·min^{-1}. The temperature of the transfer line was 250 ºC. The mass spectrometer was operated in electron impact mode (70 eV), with a mass scanning range from 35 to 350 m/z at 3.33 scans/s. Identification of volatile compounds was performed by analysing the fragmentation patterns displayed in the mass spectra, compared with the mass spectra available from a data library provided by the NIST 2014 equipment (National Institute of Standards & Technology, USA), as well as through the linear retention index compared to that of authentic compounds analysed under similar conditions. The linear retention index of each compound was calculated using the retention times of a homologous series of n-alkanes C8-C20.

The volatile compounds were semi-quantified by extrapolation of the integrated area of the internal standard of 1,2-dichlorobenzene obtained from the chromatograms of total ions (added to each analysis) to the integrated area of each compound, using a response factor of 1. The results were expressed as ng·100 g^{-1} of chicken breast. Each sample was analysed in triplicate. The methodology followed the procedures reported by Madruga, Elmore, Oruna-Concha, Balagiannis, & Mottram (2010).

2.3. Aromatic sensory profile of broiler breasts

The sensory profile based on the aroma descriptors of WS breast was characterized by trained panellists and compared to the sensory aroma profile of N breasts. Sensory analysis was performed at the initial storage time (t=0), and after 11 days of refrigerated storage and 90 days of frozen storage. We also submitted all samples for microbiological analysis to ensure that

they conformed to Brazilian legislation (Brasil, 2001). Prior to the start of sensory evaluations, all panellists signed an informed consent form, approved by the Ethics and Research Committee of the Federal University of Paraíba (CAAE 26383519.3.0000.5188), meeting the ethical and scientific standards of the Resolution n° 466 of National Health Council (Brasil, 2012).

2.3.1. Broiler breasts preparation

Both raw and roasted breast meats (WS and N) were evaluated. Frozen samples were thawed before analysis. The samples were roasted in a gas oven, and monitored with a thermocouple (Hanna Instruments, HI 935005, Romania), until an internal temperature of 75 °C was reached.

Thereafter, the samples were kept at room temperature for 3 min before serving. The panellists received a 10 g portion of the WS and N meats (2 x 2 x 2 cm), served in a cylindrical, transparent, and odourless 40 mL glass container with a lid. All samples were coded with random numbers comprised of three digits. Each sample was evaluated individually. A glass of water (150 mL) was supplied to cleanse the palate between each sample testing.

2.3.2. Sensory evaluation

A total of 15 (fifteen) volunteers were recruited amongst students and employees from the Federal University of Paraíba, Brazil, aged between 21 and 59 years old, according to their availability to participate in both training and evaluation sessions. All had previous experience with sensory evaluation of meat and/or derivatives (Rocha et al., 2022).

2.3.3. Quantitative Descriptive Analysis (QDA)

The aromatic sensory profile of the samples was determined according to the Quantitative Descriptive Analysis proposed by Stone, Sidel, Oliver, Woosley, & Singleton (1974). Training session were supervised by an appointed session lead. Initial terms to describe the sensory

profile were selected and defined to create a reference associated with each specific term. A descriptive evaluation form was generated between all panellists with each term having an unstructured scale from 1-10, 1 being "none/weak" and 10 being "strong". Thereafter, the team lead read each of the descriptors and panellists recorded their answers for each type of breast in triplicate.

The results obtained were analysed by univariate analysis of variance (ANOVA) with two sources of variation (sample and repetition). The significance values (p-value) for F_{sample} and $F_{repetition}$ for each panellist were considered, and the individuals with $pF_{sample} < 0.30$, $pF_{repetition} > 0.05$ and consensus with the other panellists for at least 80% of the descriptors were selected. The training stage was completed when the team lead observed that the panellists could accurately discriminate between N and WS samples of chicken breast. As a result, 12 trained panellists were appointed.

Finally, the trained panellists evaluated each of the samples to determine aromatic sensory profiles. For this session, the final terms agreed in training sessions alongside respective descriptors and references, were used (Table 6). The samples were evaluated in triplicate in different sessions, modifying the order of presentation of them between the panellists and between each repetition.

2.4. Statistical analysis

The Shapiro-Wilk test was used for testing normality ($\alpha = 0.05$). WS and N breasts mean values were compared using Student's t-test ($p < 0.05$). A one-way ANOVA was carried out to evaluate the changes during storage, and post-hoc Tukey's test ($p < 0.05$) was applied to compare the means. Sensory responses were analysed using univariate analysis of variance (ANOVA) to assess the sample effect with Tukey mean test ($p<0.05$), and t-test (two-tailed) to evaluate the

184 effect of the storage time ($p \leq 0.05$). Principal Component Analysis (PCA) was also performed.
185 Data were analysed using XLSTAT (version 2014.5.03, Addinsoft, New York, USA).

186 **3. Results and discussion**

187 *3.1. Volatile profile of raw WS and N broiler breasts stored under refrigeration and freezing*

188 The total number of volatile compounds identified in raw WS and N breasts ranged from 21 to
189 50, which were distributed into 9 classes: aldehydes, alcohols, ketones, aromatics, terpenes,
190 furans, hydrocarbons, phenols and sulfurates (Figure 1A, Tables 1 and 2). Before storage under
191 refrigeration or freezing (t = 0, Figure 1A), WS showed a higher concentration and number of
192 volatile compounds (132.2 $ng \cdot 100g^{-1}$ and 38 compounds) compared to N breast (59.4 $ng \cdot 100g^{-1}$
193 and 21 compounds). This variation probably resulted from the increase in the fat content
194 observed in WS breast compared to N (Kuttappan et al., 2012; Kuttappan, Hargis, & Owens,
195 2016; Mudalal, Lorenzi, Soglia, Cavani, & Petracci, 2015; Petracci, Mudalal, Babini, & Cavani,
196 2014; Tijare et al., 2016; Giampietro-Ganeco et al., 2021).

197 There were differences according to the method of cold storage (Figure 1A); in N breasts, there
198 was an increase in the total number of volatile compounds (from 21 to 25) and a decrease in the
199 number of volatile compounds in WS (from 38 to 30) when refrigerated. However, when frozen
200 there was an increase in the number of volatile compounds for both meats (N: from 21 to 30;
201 WS: from 38 to 50).

202 Conversely, from the perspective of volatile compounds concentration ($ng \cdot 100g^{-1}$), we observed
203 that their concentration decreased in the WS and N breasts during the refrigerated storage
204 (Figure 1A). There was also a ~50% reduction in the volatile compound's concentration of WS,
205 from 100.2 to 49.7 $ng \cdot 100g^{-1}$. Possibly this reduction indicates a decrease in lipid oxidation

levels throughout storage, since the volatiles identified mostly come from lipid degradation (Rocha et al., 2020; Estévez, 2015; Pereira et al., 2022).

We observed that frozen breasts had higher volatile concentrations when compared to refrigeration, ranging from 144.5 to 100.2 ng·100g^{-1} for WS, and from 137.1 to 67.6 ng·100g^{-1} for N over 90 days (Figure 1A). Considering that lipid oxidation is always accompanied by the degradation of unsaturated fatty acids, especially after long-term frozen storage, this factor probably indicates the tendency to increased concentrations of volatile compounds under such condition (Qi et al., 2021). Thus, comparing refrigeration and freezing, the temperature difference (1 ºC for refrigeration and -18 ºC for freezing) corroborates this fact, since cooled meats suffer greater oxidative damage than frozen ones (Warris, 2000).

Lipid oxidation can still affect raw breasts during frozen storage because thawed water is available for lipid oxidation in its initiation phase. In addition, during thawing, pro-oxidant agents such as free iron and haemoglobin, released by organelle rupture, can react with hydrogen peroxide to generate hydroxyl radicals, thus accelerating lipid oxidation (Swatland, 2004; Qi et al., 2021; Mariutti & Bragagnolo, 2009).

Regarding the various volatile classes that were detected in raw WS and N meats, we observed that both had higher concentrations of aldehydes regardless of storage condition (Figure 1B, Tables 1 and 2). The aldehydes were the primary volatile compound detected in raw WS and N breasts, contributing up to 92% and 77% of total volatile compounds, respectively.

Refrigeration of WS breasts resulted in a decrease in the concentration (ng·100 g^{-1}) of aldehydes (t0 = 75.5; t11 = 38.6; t14 = 34.5). WS (frozen) and N breasts (cooled and frozen) had higher concentrations during the intermediate storage period, i.e., at 45 days of freezing (N: 124.8 ng·100 g^{-1} and WS: 110.6 ng·100 g^{-1}) and 11 days of refrigeration (N: 79.9 ng·100 g^{-1}). At the end of storage, a reduction in aldehyde concentrations ranging from 54.3% (refrigerated WS)

to 19% (frozen N) was observed. However, frozen WS breasts showed an increase of 26.3% in aldehydes; these differences were significant, both in relation to breasts ($p<0.05$) and storage time ($p<0.05$). The higher content of aldehydes corroborates that described by Tasoniero, Cullere, Cecchinato, Puolanne, & Dalle Zotte (2016) who traced a sensory profile of poultry meat, where a more rancid profile was attributed to chicken breasts with *White Striping* disorder when compared to normal ones.

According to Mottram (1998), the characteristic flavour of the different meat types is the result of the constitution and degradation of the lipid material, and aldehydes are the main product of this degradation. The author points out that the higher proportion of unsaturated fatty acids in chicken and pork meat, compared to beef or lamb, results in more unsaturated volatile aldehydes in these meats; such compounds may be important in determining the specific aromas of these meat products. This author also cited that ketones and alcohols are important for specific meat flavours.

Alcohols and ketones were also highly abundant aromatic compounds detected throughout the refrigeration and freezing (Figures 1C and 1D). Alcohols were the second most abundant volatile compound class in the broiler breasts, with a significant increase ($p<0.05$) in concentration throughout the freezing period in both N and WS meats. However, the concentrations of alcohol in WS breasts were ~3x higher compared to N (Figure 1C, Table 2). Frozen WS breasts have increased concentrations of both alcohols (from 20.47 to 39.10 ng·100 g^{-1}) and ketones (from 2.35 to 5.45 ng·100 g^{-1}) during freezing. Whilst under refrigeration these concentrations were reduced (alcohols: 20.47 to 7.04 ng·100 g^{-1}; ketones: 2.35 to 0.5 ng·100 g^{-1}).

In frozen N breasts, the concentrations of alcohols tended to increase from 5.57 to 9.18 ng·100 g^{-1}, while those of ketones were reduced from 1.49 to 1.25 ng·100 g^{-1}.

Two major alcohols were identified from breasts, these were: 1-octen-3-ol (mushroom, mould, and fermented odours) and 1-octanol (penetrating aromatic odour, fatty, cerous, citrus, oily) (Calkins & Hodgen, 2007; Ba, Hwang, Jeong, & Touseef, 2012). According to Chmiel, Daisley, Pitek, Thompson, & Reid (2020), 1-pentanol, ethylhexanol and oct-1-en-3-ol are the predominant alcohols identified in refrigerated chicken breasts.

Other detected volatile compounds including aromatics, terpenes, furans, hydrocarbons, phenols and sulfurates that were identified during raw refrigerated and frozen WS and N breasts (Tables 1 and 2), had concentrations of 7.14 ng·100 g^{-1} and 6.92 ng·100 g^{-1}, for WS and N breasts, respectively. When frozen, phenol (2,4-di-t-Butylphenol) was the least prevalent among the volatile compounds, with concentrations of 3.49 ng·100 g^{-1} and 3.23 ng·100 g^{-1} for N and WS, respectively, after 45 days of frozen storage.

Volatile compounds with higher concentrations in refrigerated samples were hexanal (green and greasy odour), octanal (green, lemon, citrus and aldehyde odour) and nonanal (sweet, fatty and green odour) (Table 1). Amongst these, octanal had the highest concentration throughout the storage period for both types of breasts, although the N had a greater concentration than WS. According to Jayasena, Ahn, Nam, & Jo (2013), 2,4-decadienal has a more prominent aroma in chicken meat, compared to hexanal, due to its lower odour threshold. An explanation for the prominence of the aldehyde in chicken meat is that the development of these volatiles occurs as a result of the oxidation of fatty acids and intramuscular phospholipids.

2,4-decadienal was detected only in the WS at storage time t0 (Table 1). We also observed that the prevalence and abundance of volatile compounds we identified in the WS and N chicken breasts are in agreement with other literature investigating volatile compounds in chicken meat (Mottram, 1998; Madruga et al., 2009; Rochat & Chaintreau, 2005; Ba et al., 2012).

3.2. Volatile profile of roasted WS and N broiler breasts stored under refrigeration and freezing

The number of volatile compounds identified in roasted chicken breasts ranged from 60 (WS; t0) to 30 (WS; t14). These included a total of 10 different classes: aldehydes, alcohols, ketones, aromatics, terpenes, hydrocarbons, sulphurs, pyridines and phenols (Figure 2A, Tables 3 and 4). The total number of volatiles identified in the roasted breasts (Figure 2A) was ~2 times higher than the number identified in raw breasts (Figure 1A), except for refrigerated (t11 and t14) and frozen (t90) WS and refrigerated (t14) N breasts. This is due to various thermal reactions including: Maillard reaction, thermal degradation of lipids, proteins and thiamine, amino acid pyrolysis, lipid oxidation, Maillard-lipid interactions (Chansataporn, Prathumars, Nopharatana, Siriwattanayotin, & Tangduangdee, 2019; Brunton, Cronin, & Monahan, 2002).

WS had a greater number of volatile compounds compared to N, regardless of storage condition. When refrigeration was used, there was a ~50% decrease in the concentrations of volatiles, in both breasts. When frozen, N had an increased amount of volatiles after 45 days (from 50 to 51), whilst there was a decrease in the number of volatile compounds (from 60 to 55) in WS (Figure 2A).

The concentrations of volatile compounds in refrigerated roasted broiler breasts were up to 10x higher compared to raw breasts at t0 (Figure 2A). Considering that heat treatment triggers a series of chemical reactions which result in the development of the characteristic flavour of roasted meat, this increase in volatile compounds concentration was expected.

When evaluating roasted meat samples during refrigerated storage, we observed that both WS and N breasts had a significant reduction ($p<0.05$) in the concentration of volatiles throughout storage (Table 3). In WS, aldehydes and alcohols had initial concentrations of ~1000 and ~200 ng·100 g^{-1}, which decreased to ~70 and ~10 ng·100 g^{-1}, respectively, after 14 days. In N roasted

301 broiler breasts, we observed an increase in volatiles concentration in the first 11 days, followed
302 by a reduction after 14 days (Figure 2A).

303 Amongst roasted breasts, the most prevalent volatile compounds were aldehydes, followed by
304 alcohols and ketones (Figures 2B, 2C, and 2D). Aldehydes (mainly hexanal, nonanal and
305 octanal) contributed up to 83% of volatiles in WS and 87% in N once cooled (Table 3).

306 As previously described, at t0, there were high concentrations of hexanal, 604.13 ng·100 g^{-1} in
307 WS roasted and 258.29 ng·100 g^{-1} in roasted N. Once heat-treated, breasts typically undergo a
308 rapid and intense deterioration of flavour when cold-stored – this phenomenon is referred to as
309 warmed-over flavour (WOF) (Pegg & Shahidi, 2012).

310 This unpleasant flavour, which may be responsible for consumer rejection and relevant
311 economic losses is related to the formation of specific lipid-derived volatiles such as pentanal,
312 hexanal and alkenes (Jayasena et al., 2013). This deterioration process is particularly relevant
313 in chicken meat due to its high degree of unsaturated fat which is susceptible to oxidative
314 reactions (Carvalho, Shimokomaki, & Estévez, 2017).

315 The volatile classes derived from thermally treated chicken breasts stored under refrigeration
316 and freezing all had concentrations <20 ng·100 g^{-1}. The main compound observed was 2-
317 pentylfuran, which constituted approximately 90% of all volatiles with a concentration of 10.12
318 ng·100 g^{-1} and 15.57 ng·100 g^{-1} in N and WS, respectively, at t0.

319 The volatile compound profiles of roasted WS and N chicken breasts that were frozen were
320 similar to those that were refrigerated, though the volatiles concentrations were ~10 times
321 higher. The reduction of these compounds during the freezing period was significantly different
322 ($p<0.05$), although less intense when compared to refrigerated breasts (Figure 2A; Table 4).

Similar volatile compounds were observed in both breasts; aldehydes contributed ~78 % and ~80 % share in roasted WS and N, respectively, followed by alcohols and ketones (Figures 2B, 2C, and 2D). The main compounds observed were hexanal, nonanal and octanal (Table 4). These aldehydes act as main contributors to the development of the flavour of poultry meat.

WS roasted breasts maintained the same number and concentration of volatiles throughout freezing storage (90 days). This indicates the preservation of volatiles in storage under freezing temperature, whereas under refrigeration there was a significant reduction of volatiles after 11 days of storage at 1 °C.

3.3 Sensory aroma profile of WS and N broiler breasts stored under refrigeration and freezing

The aroma profile of raw and roasted broiler breasts consisted of seven attributes. Three of these (sweet, metallic and rancid aroma) were associated with roasted and raw breasts, two (fresh chicken aroma and strange aroma) were only observed in raw samples, and two (cooked chicken aroma and fish aroma) were only mentioned in roasted samples. Table 5 shows the average results of the intensity of these attributes and the influence of time, storage condition and *White Striping* disorder on the aroma attributes of raw and roasted chicken breast.

In the raw breast evaluation, we observed that the aroma of "fresh chicken" was more intense in all samples, with averages ranging from 5 to 9 (on the 1-10 scale). The other aromatic descriptors had lower intensities, with mean values ranging from ~1 to ~3, indicating the low contribution of these attributes in the aromatic profile of the raw samples. The "fresh chicken" aroma can be related to the lower number and concentration of volatiles, besides the perceived odour of fresh chicken. The odour perception is related predominantly to octanal, which gives the green, lemon, citrus and aldehyde odour (Ba et al., 2012).

During refrigeration, storage time had no influence on the sensory aroma profile of raw samples. There was a significant difference in metallic aroma between N and WS samples only at 11 days of storage. A study by Katiyo, de Kock, Coorey, & Buys (2020) indicates that as microbial levels increase in chicken meat stored under refrigeration, so does the intensity of off-odours. However, negative attributes associated with off-odours were only identified in the present study in the WS sample at 11 days of storage. Thus, by considering the odour intensity, we suggest that up to 11 days of storage, N and WS refrigerated chicken breasts can be considered semi-fresh.

The time and the presence of myopathy in frozen raw breasts strongly influenced the aromatic profile when compared to those under refrigeration. Sweet and rancid aromas were identified in both samples at 90 days of storage, where WS was identified ($p<0.05$). According to Petracci et al. (2019), although lipid content is generally higher in WS chicken breasts, these do not seem to be more susceptible to lipid oxidation than normal ones. However, our study proves that it is possible to detect a rancid aroma consequent of the lipid oxidation process, which is markedly more intense in WS chicken. There was a significant reduction in the metallic attribute at 90 days of storage for both samples. For the attribute "fresh chicken" aroma, the storage time had a negative effect on the N sample, with a reduced intensity of this aroma. Conversely, WS sample remained stable, which caused a significant difference between N and WS samples at 90 days of freezing storage. Thus, we can infer that freezing storage preserved the aroma profile of the samples, except for the attribute of “fresh chicken” aroma in N samples at 90 days, where panellists recorded this aroma as a medium intensity.

Regarding the sensory aroma profile of roasted breasts, the characteristic odour of "cooked chicken" was the most intensely reported, with mean values between 7.81 and 9.63; for the other descriptors, the evaluation ranged from 0.53 to 3.81. The flavour of cooked chicken meat is derived through the Maillard reaction, lipid degradation and the interaction between these

two reactions (Jayasena et al., 2013). This aroma is composed of a set of aromatic notes formed during cooking and is related to the increase in the number and concentration of volatiles compared to raw samples. Volatile compounds are generated during thermal processing and the flavour of meat is determined by the resulting mixture of these compounds, most of which are generated through lipid degradation, mainly the oxidation of fatty acid components (Jayasena et al., 2013, Estevez, 2015; Qi et al., 2021).

Significant differences were observed between "rancid" and other attributes for roasted N and WS samples throughout cold storage. Under refrigerated storage, the presence of WS significantly influenced the lower intensity of "sweet", "cooked chicken" and "metallic" attributes at t0. At the end of cold storage, there was a significant reduction in the intensity of "sweet", "metallic", "rancid" and "fishy" aromas in roasted N and WS. When frozen, there was a significant increase in the "sweet" aroma, observed after 90 days for both samples. For the N, there was a reduction in "metallic" and "rancid" attributes during the same period. We also noted that the latter two were only detected in WS at the end of frozen storage. The presence of myopathy led to a lower intensity of "sweet" and "cooked chicken", and higher intensity of "fishy", which are aromatic attributes associated with common off-odours in normal chicken meat or affected with some disorder (Tasoniero et al., 2016). The "fishy" aroma was only noticeable in the roasted samples in the present study. This aroma has already been identified in samples of raw chicken thighs stored under refrigeration (Katiyo et al., 2020), and was also at low intensity (<1) in cooked chicken breast (Tasoniero et al., 2016). Thus, the storage time, when freezing, resulted in small changes in less intense aromas in the chicken breast after thermal processing, but no influence on the intensity of the most characteristic attribute of these samples (Cooked Chicken).

3.4 PCA of raw and roasted WS and N broiler breasts stored under refrigeration and freezing

The first two principal components, referring to the volatiles class and sensory attributes of raw N and WS Chicken breasts, explained 72.47 % of the data variance (Figure 3A). The axes PC1 (F1) and PC2 (F2) (51.69% and 20.78%, respectively) explained the variance. The PC1 axis discriminated the types of meat and the storage period whilst frozen, whereas PC2 discriminated the types of breasts and storage time when refrigerated. Regardless of the type of storage, the N and WS showed clear separation from each other.

During refrigeration, we noted that N breasts on days 0 and 11 are in the third quadrant (negative PC1 and PC2), whereas WS chicken breasts in time 0 and 11 days are located in the fourth quadrant (negative PC1 and positive PC2), respectively. N breasts stored for 11 days were best described by the high proportion of phenol volatile compounds. WS meat, during the same storage period, was described by the presence of an unpleasant odour, characteristic of aromatic, terpene and metallic volatile compounds.

During freezing (Figure 3A), raw WS chicken breasts - after 90 days of storage - were better described by rancid attributes and mainly by the presence of volatile aldehydes, alcohols, ketones, hydrocarbons, furans, esters and pyridines. These volatile compounds originated from lipid oxidation indicating that in this storage period (90 days), the freezing storage did not strongly inhibit the oxidative processes of WS chicken breasts compared to N. Lipid oxidation is one of the most important causes of deterioration in meat and meat products and is linked to primarily unsaturated and polyunsaturated fatty acids (Sohaib et al., 2017). Chicken meat contains a higher proportion of polyunsaturated fatty acids compared to other meats, which makes it more susceptible to oxidative deterioration and consequently the formation of undesirable volatile compounds. However, in our study, we show that the perception of this aroma is low (~2), reinforcing that the concentration of these compounds in the samples may not be an important factor for consumers. A small variation was observed between the N

samples between 0 and 90 days of storage under freezing, though both were located in the same quadrant, indicating greater stability in these conditions.

The first two principal components explained 70.72 % of the data variance, 42.17 % explained by PC1 and 28.55 % by PC2. PC1 is positively related to the metallic aroma and volatile classes of aldehyde, ketone, alcohol, furan, hydrocarbons, terpenes and pyridine. PC2 is positively related to the sensory attributes of roasted chicken aromas and the presence of phenol volatiles and sulphur compounds. The roasted N samples had similar profiles even after 90 days of freezing storage, being better characterized by compounds of the phenol class and the attributes “cooked chicken”, “sweet”, “fishy”, and “rancid”. The latter two are considered off-flavour, however, due to their low intensity, these aromas had little contribution to the deterioration of sample quality. Conversely, roasted WS at t0, located in quadrant 1, has an aromatic profile mainly influenced by furan, ketone, terpene, aldehyde and pyridine volatiles, whereas after 90 days of storage, located in quadrant 2, it was better characterized mainly by sulphur volatiles. As such, there is the possibility of increased formation of volatile compounds containing sulphur via amino acids such as cysteine, cystine and methionine (Katiyo et al., 2020), but at insufficient levels to perceive an unpleasant or sulphurous aroma. These results show that the aroma of roasted chicken breasts is influenced not only by the type of sample (N and WS), but also by the type of storage (refrigerated or frozen).

4. Conclusion

Raw chicken meat without myopathy disorder was characterized by aromatic compounds including alcohols, aldehydes, furans, ketones, phenols and terpenes, and by the sensory attributes "sweet aroma", "fresh chicken" and "metallic". Raw WS breasts also exhibited aromatic, ester and hydrocarbon compounds (but no phenols) and were described by the sensory aromas "fresh chicken" and "metallic". Roasted N breasts were characterized by alcohols,

444 aldehydes, aromatics, pyridines, furans, hydrocarbons, ketones, phenols, sulphurs and terpenes,
445 in addition to the sensory aromatic attributes "sweet aroma", "cooked chicken", "metallic",
446 "rancid" and "fishy". Roasted WS meat was also characterised by these compounds (except
447 phenol), and the aromas "rancid" and "fishy". During storage under refrigeration, there was a
448 reduction in the number of compounds, and in the concentration of these compounds (especially
449 the aldehyde, alcohol and ketone classes), in both raw and roasted WS and N. In frozen meat,
450 there was an increase in the concentration and number of compounds in raw WS (especially
451 aldehydes, alcohol and ketones), which was the opposite of roasted WS. Sensory aromatic
452 profiles indicated that refrigeration preserved the aromatic quality of both raw samples. When
453 frozen for 90 days, the presence of myopathy (raw sample) slightly influenced the aromatic
454 profile, maintaining the most characteristic aroma "fresh chicken" but also showed a slight
455 increase in "sweet aroma" and "rancid". Throughout the frozen storage, there was an increase
456 in "sweet" aroma, but also the emergence of "rancid" and "fishy" aromas from the roasted WS
457 meat. This indicates that the sensory and chemical aromatic profiles of chicken breasts were
458 influenced not only by the presence of myopathy (WS), but also by the type of storage
459 (refrigerated or frozen), and how the breasts were presented (raw or roasted). However, future
460 studies with consumers are recommended to further investigate the implications of aromatic
461 profiles and correlate this to the acceptability of chicken meat with WS, under different storage
462 conditions.

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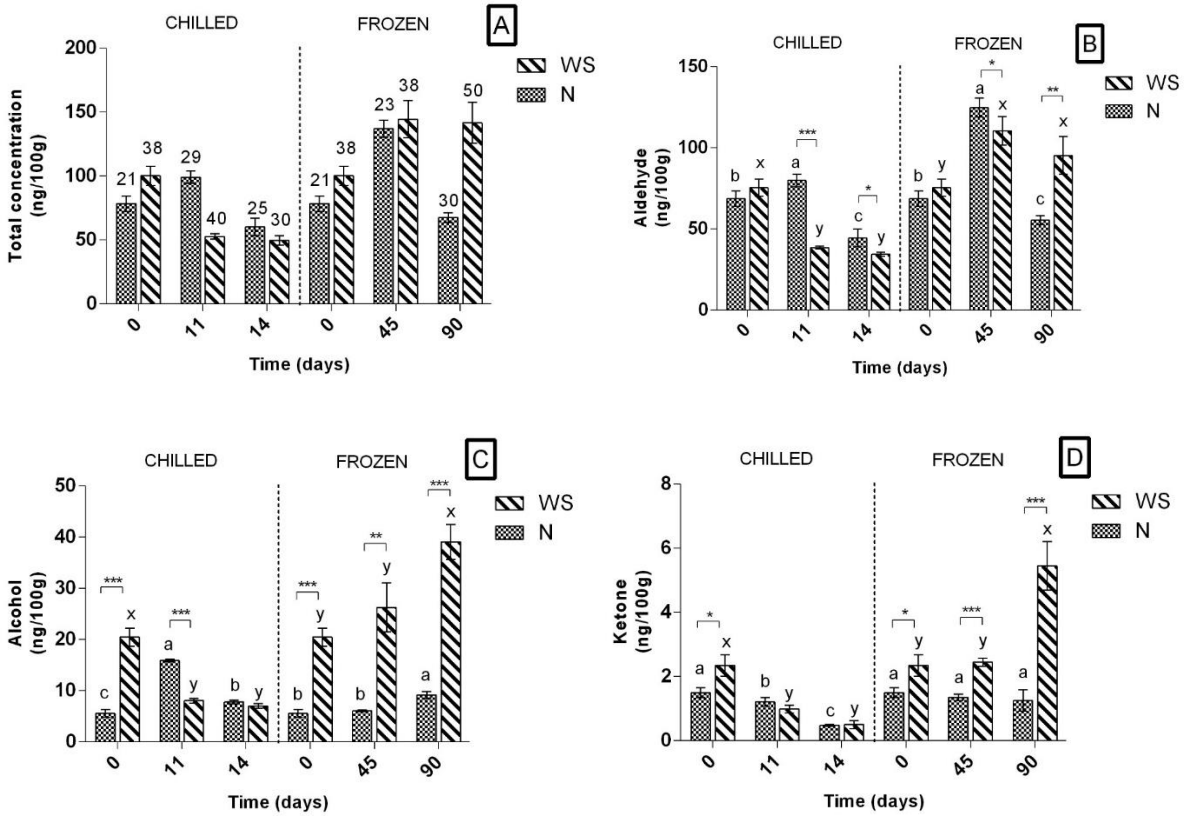
Figure 1 - Concentration of volatile compounds from raw WS chicken breast stored under refrigeration and freezing.



Note: Number and total concentration of volatile compounds (A), concentration of aldehydes (B), concentration of alcohols (C), and concentration of ketones (D).

N: Normal meat. WS: White Striping myopathy.

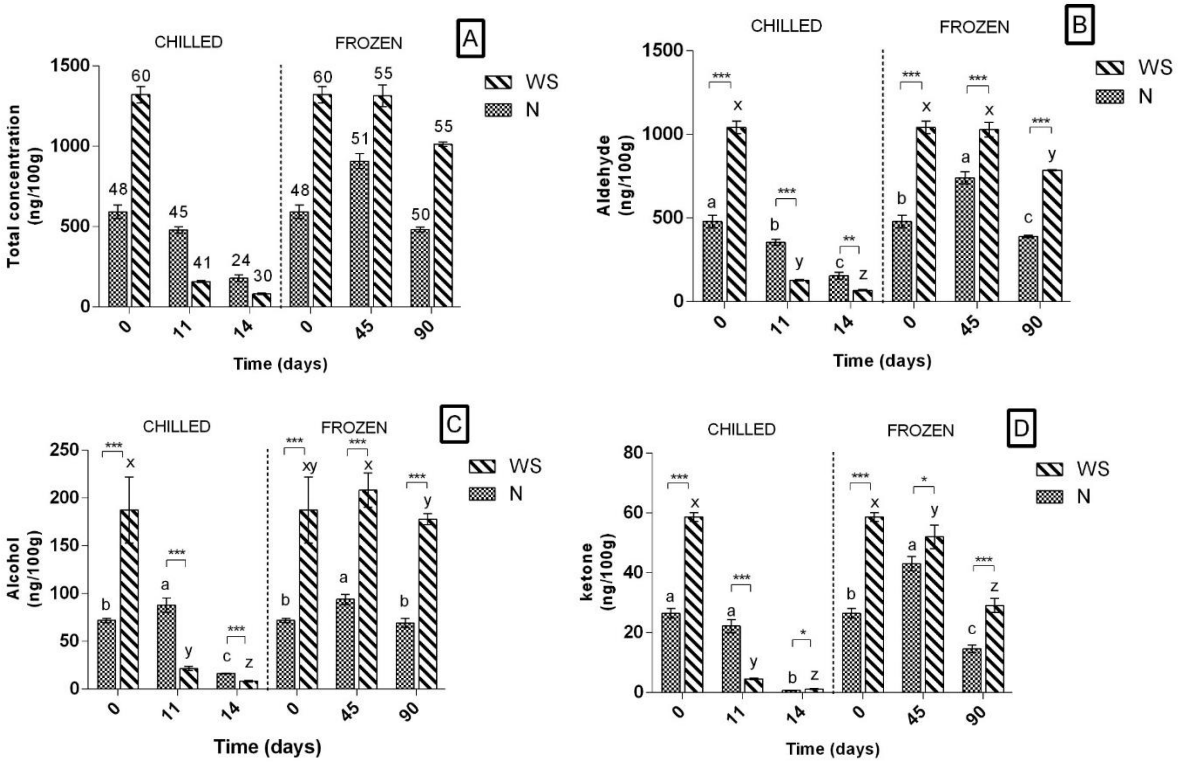
Different letters differ significantly by Tukey's test ($p<0.05$).

a,b,c letters represent the comparative analysis between storage times of N meat.

x,y,z letters represent the comparative analysis between storage times of WS meat.

Asterisk represents a significant difference between breast meat by the t-Student test (*: $p<0.05$, **: $p<0.01$, ***: $p<0.001$).

Figure 2 - Concentration of volatile compounds from roasted WS chicken breast stored under refrigeration and freezing.



Note: Number and total concentration of volatile compounds (A), concentration of aldehydes (B), concentration of alcohols (C), and concentration of ketones (D).

N: Normal meat. WS: White Striping myopathy.

Different letters differ significantly by Tukey's test ($p<0.05$).

a,b,c letters represent the comparative analysis between storage times of N meat.

x,y,z letters represent the comparative analysis between storage times of WS meat.

* represents a significant difference between breast meats by the t-Student test (*: $p<0.05$, **: $p<0.01$, ***: $p<0.001$).

Figure 3 - Principal Component Analysis (PCA) of WS chicken meat (Raw (A) and Roasted (B)) during refrigerated and frozen storage.

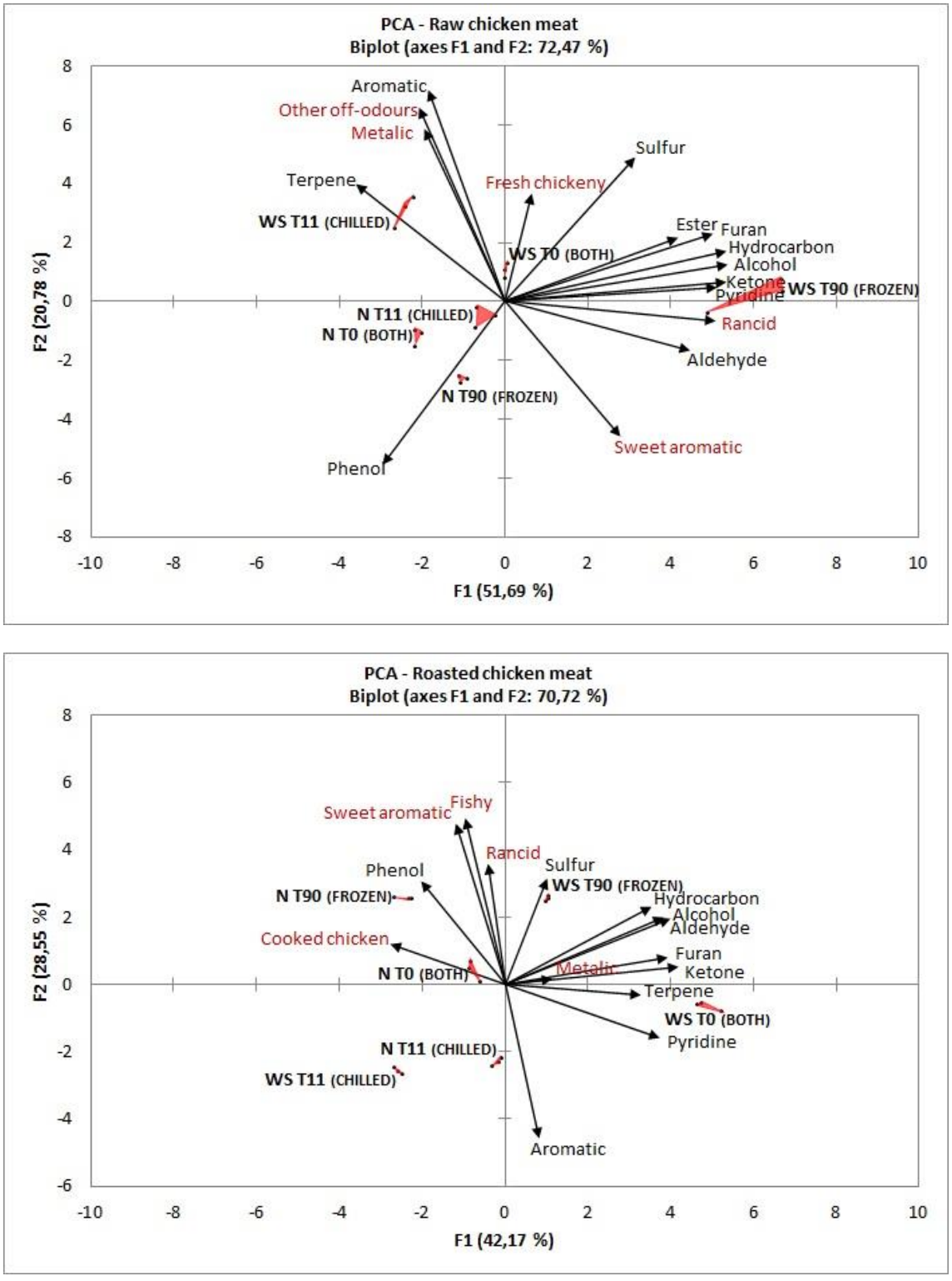


Table 1. Profile of volatile compounds (ng/100g) in raw N and WS chicken breasts at 0, 11 and 14 days of refrigerated storage.

Class/Compound	**LRI**	**N**			**WS**		
		T0	**T11**	**T14**	**T0**	**T11**	**T14**
Aldehyde (20)		**68.79±4.83**	**79.88±3.98**	**44.46±5.54**	**75.49±5.22**	**38.60±0.82**	**34.45±1.30**
Pentanal	<800	0.95±0.14	1.09±0.15	0.80±0.06	2.27±0.24	0.88±0.11	0.62±0.15
Hexanal	800	12.42±0.36	32.89±1.53	7.85±0.52	26.90±3.17	11.46±1.07	8.76±0.52
Heptanal	901	0.64±0.08	1.46±0.17	0.50±0.02	2.55±0.42	0.82±0.05	0.41±0.09
(Z)-2-Heptenal	955	0.09±0.02	0.37±0.02	0.03±0.01	0.62±0.09	0.15±0.03	0.03±0.01
Benzaldehyde	958	-	-	-	0.26±0.05	0.81±0.20	0.73±0.07
Octanal	1003	52.49±3.95	38.28±2.03	33.09±4.85	29.42±2.42	20.71±1.59	21.51±0.84
Benzeneacetaldehyde	1043	-	0.11±0.02	-	0.20±0.04	0.02±0.00	-
(E)-2-Octenal	1057	0.09±0.01	0.30±0.06	0.06±0.02	0.98±0.14	0.18±0.02	0.02±0.01
Nonanal	1105	2.11±0.27	4.62±0.55	2.02±0.23	10.18±1.49	3.05±0.27	2.20±0.03
3-Ethylbenzaldehyde	1162	-	0.13±0.05	-	0.26±0.06?	0.04±0.00	-
(Z)-4-Decen-1-al	1194	-	-	-	0.04±0.01	0.02±0.00	0.02±0.00
Decanal	1205	-	0.41±0.05	0.08±0.02	0.48±0.01	0.19±0.03	0.08±0.03
2,4-Nonadienal	1214	-	-	-	0.19±0.02	0.05±0.01	0.04±0.00
(E)-2-Decenal	1262	-	0.10±0.03	0.02±0.01	0.41±0.03	0.07±0.02	-

Undecanal	1307	-	-	-	0.06±0.02	0.01±0.01	-
2,4-Decadienal	1317	-	-	-	0.18±0.02	-	-
2-Undecenal	1364	-	-	-	0.26±0.06	0.02±0.01	-
Dodecanal	1409	-	0.14±0.04	-	0.20±0.03	0.08±0.01	0.04±0.01
Tridecanal	1511	-	-	-	-	0.03±0.02	-
Tetradecanal	1613	-	-	-	-	0.03±0.02	-
Alcohol (12)		**5.56±0.74**	**15.90±0.26**	**7.80±0.38**	**20.47±1.81**	**8.05±0.49**	**7.04±0.48**
3-Methyl-1-butanol	<800	-	-	0.39±0.07	-	-	1.66±0.15
Pentanol	<800	0.82±0.13	2.11±0.13	1.31±0.14	2.24±0.20	1.02±0.19	0.61±0.04
Hexanol	867	0.19±0.03	0.47±0.09	0.22±0.05	0.34±0.07	0.32±0.07	0.31±0.06
Heptanol	970	0.40±0.03	1.23±0.06	0.31±0.02	2.10±0.24	0.88±0.05	0.34±0.06
1-Octen-3-ol	980	2.51±0.35	9.13±0.09	2.60±0.34	10.70±1.45	3.82±0.17	2.53±0.10
4-Ethylcyclohexanol	998	-	-	-	0.15±0.04	0.05±0.01	0.03±0.00
2-Ethyl-1-hexanol	1030	1.07±0.11	-	1.72±0.11	-	-	0.82±0.08
(E)-2-Octen-1-ol	1069	0.16±0.02	0.69±0.09	0.40±0.05	0.96±0.06	0.39±0.04	0.20±0.04
Octanol	1071	0.41±0.07	2.18±0.07	0.80±0.11	3.74±0.07	1.46±0.13	0.54±0.11
1-Nonen-4-ol	1095	-	-	-	0.17±0.03	0.08±0.01	-
Nonanol	1172	-	0.10±0.02	-	0.07±0.01	0.03±0.00	-

Decanol	1266	-	-	0.03±0.02	-	-	-
Ketone (3)		**1.50±0.15**	**1.21±0.13**	**0.48±0.02**	**2.35±0.33**	**0.99±0.12**	**0.50±0.13**
2-Heptanone	890	0.17±0.02	0.15±0.02	0.08±0.01	0.18±0.04	0.10±0.01	0.06±0.01
2,5-Octanedione	985	0.72±0.09	0.84±0.12	0.40±0.01	1.85±0.33	0.80±0.12	0.41±0.15
3-Dodecanone	1400	0.61±0.04	0.22±0.05	-	0.31±0.04	0.08±0.02	0.03±0.01
Aromatic (1)		**-**	**-**	**6.92±0.85**	**0.63±0.06**	**3.82±0.35**	**7.14±1.78**
Naphthalene	1181	-	-	6.92±0.85	0.63±0.06	3.82±0.35	7.14±1.78
Terpene (2)		**0.58±0.06**	**0.45±0.01**	**0.36±0.06**	**0.48±0.11**	**0.55±0.08**	**0.38±0.07**
o-Cymene	1025	0.08±0.02	0.06±0.01	-	0.03±0.01	0.03±0.01	0.02±0.00
Limonene	1027	0.50±0.04	0.39±0.01	0.36±0.06	0.46±0.10	0.52±0.07	0.36±0.07
Furan (2)		**0.10±0.04**	**0.31±0.05**	**0.10±0.04**	**0.62±0.06**	**0.22±0.03**	**0.11±0.02**
2-Pentylfuran	991	0.10±0.04	0.19±0.04	0.10±0.04	0.47±0.02	0.15±0.01	0.06±0.01
2-Octylfuran	1294	-	0.12±0.01	-	0.15±0.04	0.07±0.02	0.05±0.01
Hydrocarbon (3)		**-**	**0.05±0.01**	**-**	**0.10±0.02**	**0.03±0.01**	**-**
Dodecane	1199	-	-	-	0.03±0.00	-	-
Tridecane	1300	-	0.05±0.01	-	0.04±0.02	0.03±0.01	-
Pentadecane	1499	-	-	-	0.03±0.01	-	-
Phenol (1)		**1.90±0.23**	**1.27±0.25**	**0.04±0.00**	**-**	**0.45±0.27**	**-**

2,4-di-t-Butylphenol	1513	1.90±0.23	1.27±0.25	0.04±0.00	-	0.45±0.27	-
Sulfur (1)		**-**	**-**	**0.04±0.00**	**-**	**0.03±0.01**	**0.05±0.00**
Benzothiophene	1188	-	-	0.04±0.00	-	0.03±0.01	0.05±0.00

LRI: Linear retention indices. N: Normal meat. WS: White Striping myopathy.

Table 2. Profile of volatile compounds (ng/100g) in raw N and WS chicken breasts at 0, 45 and 90 days of frozen storage.

Class/Compound	LRI	N			WS		
		T0	T45	T90	T0	T45	T90
Aldehyde (23)		**68.79±4.83**	**124.82±5.94**	**55.68±2.81**	**75.49±5.22**	**110.55±8.70**	**95.37±11.58**
Pentanal	<800	0.95±0.14	0.94±0.04	0.96±0.09	2.27±0.24	1.58±0.07	1.58±0.28
Hexanal	800	12.42±0.36	14.42±1.28	11.48±1.43	26.90±3.17	32.40±2.05	25.85±3.12
Heptanal	901	0.64±0.08	0.74±0.05	0.91±0.14	2.55±0.42	3.40±0.29	2.59±0.45
(Z)-2-Heptenal	955	0.09±0.02	-	0.20±0.03	0.62±0.09	0.29±0.04	0.94±0.11
Benzaldehyde	958	-	2.48±0.14	0.45±0.04	0.26±0.05	2.05±0.18	0.37±0.05
Octanal	1003	52.49±3.95	99.74±4.87	37.48±2.26	29.42±2.42	59.46±4.18	29.10±1.63
Benzeneacetaldehyde	1043	-	0.26±0.02	0.06±0.02	0.20±0.04	0.04±0.01	0.41±0.05
(E)-2-Octenal	1057	0.09±0.01	-	0.21±0.04	0.98±0.14	0.33±0.02	2.18±0.18
Nonanal	1105	2.11±0.27	3.82±0.34	3.45±0.09	10.18±1.49	10.04±0.83	21.88±2.57
3-Ethylbenzaldehyde	1162	-	-	0.12±0.06	0.26±0.06	0.08±0.02	1.22±0.27
(Z)-4-Decen-1-al	1194	-	-	-	0.04±0.01	-	0.30±0.07
Decanal	1205	-	0.18±0.02	0.26±0.06	0.48±0.01	0.55±0.07	1.71±0.33
2,4-Nonadienal	1214	-	-	-	0.19±0.02	0.13±0.03	0.65±0.08
(E)-2-Decenal	1262	-	2.24±0.22	0.03±0.03	0.41±0.03	0.08±0.02	1.08±0.16

Undecanal	1307	-	-	0.03±0.01	0.06±0.02	0.03±0.02	0.26±0.05
2,4-Decadienal	1317	-	-	-	0.18±0.02	-	1.04±0.15
2-Undecenal	1364	-	-	-	0.26±0.06	-	0.95±0.04
2-Butyl-2-octenal	1375	-	-	-	-	-	0.10±0.03
Dodecanal	1409	-	-	0.03±0.03	0.20±0.03	0.07±0.02	0.67±0.07
Pentylbenzaldeyde	1460	-	-	-	-	-	0.06±0.03
Pentadecanal	1715	-	-	-	-	0.02±0.01	0.14±0.04
Tridecanal	1511	-	-	-	-	-	0.44±0.04
Tetradecanal	1613	-	-	-	-	0.02±0.01	0.51±0.07
Alcohol (13)		**5.56±0.74**	**6.08±0.14**	**9.18±0.68**	**20.47±1.81**	**26.29±4.81**	**39.10±3.41**
Pentanol	<800	0.82±0.13	0.84±0.09	1.19±0.11	2.24±0.20	14.78±3.73	2.01±0.22
Hexanol	867	0.19±0.03	0.18±0.04	0.27±0.06	0.34±0.07	0.52±0.03	1.12±0.24
Heptanol	970	0.40±0.03	0.55±0.02	0.89±0.09	2.10±0.24	1.27±0.26	2.64±0.17
1-Octen-3-ol	980	2.51±0.35	2.65±0.09	4.97±0.34	10.70±1.45	6.68±0.58	20.57±2.27
4-Ethylcyclohexanol	998	-	-	-	0.15±0.04	-	0.37±0.06
2-Ethyl-1-hexanol	1030	1.07±0.11	1.23±0.03	-	-	-	-
(Z)-3-Octen-1-ol	1047	-	-	-	-	-	0.11±0.01
(E)-2-Octen-1-ol	1069	0.16±0.02	0.09±0.03	0.48±0.05	0.96±0.06	0.46±0.04	3.63±0.51

Octanol	1071	0.41±0.07	0.54±0.02	1.35±0.12	3.74±0.07	2.45±0.12	6.70±0.47
1-Nonen-4-ol	1095	-	-	-	0.17±0.03	0.11±0.04	1.31±0.11
2-Nonen-1-ol	1109	-	-	-	-	-	0.03±0.02
Nonanol	1172	-	-	0.03±0.01	0.07±0.01	0.03±0.01	0.26±0.06
Decanol	1266	-	-	-	-	-	0.34±0.06
Ketone (5)		**1.50±0.15**	**1.35±0.10**	**1.25±0.03**	**2.35±0.33**	**2.45±0.13**	**5.45±0.76**
2-Heptanone	890	0.17±0.02	0.65±0.06	0.08±0.02	0.18±0.04	0.79±0.03	0.22±0.07
2,5-Octanedione	985	0.72±0.09	0.28±0.03	1.01±0.01	1.85±0.33	1.79±0.10	4.76±0.61
3-Dodecanone	1400	0.61±0.04	0.18±0.04	0.07±0.02	0.31±0.04	0.11±0.03	0.14±0.03
3-Decen-5-one	1344	-	-	-	-	-	0.13±0.02
Acetophenone	1065	-	0.24±0.05	0.10±0.03	-	0.17±0.01	0.19±0.03
Aromatic (1)		**-**	**0.90±0.01**	**0.09±0.02**	**0.63±0.06**	**1.03±0.06**	**0.22±0.04**
Naphthalene	1781	-	0.90±0.01	0.09±0.02	0.63±0.06	1.03±0.06	0.22±0.04
Terpene (2)		**0.58±0.06**	**-**	**-**	**0.48±0.11**	**0.32±0.08**	**-**
o-Cymene	1025	0.08±0.02	-	-	0.03±0.01	0.04±0.01	-
Limonene	1027	0.50±0.04	-	-	0.46±0.10	0.27±0.07	-
Furan (2)		**0.10±0.04**	**0.42±0.04**	**0.17±0.02**	**0.62±0.06**	**0.49±0.10**	**0.93±0.18**
2-Pentylfuran	1991	0.10±0.04	0.12±0.03	0.07±0.01	0.47±0.02	0.31±0.04	0.54±0.11

2-Octylfuran	1294	-	0.30±0.05	0.11±0.01	0.15±0.04	0.18±0.07	0.39±0.07
Hydrocarbon (3)		**-**	**-**	**0.02±0.01**	**0.10±0.02**	**0.07±0.02**	**0.26±0.05**
Dodecane	1199	-	-	-	0.03±0.00	0.02±0.01	0.06±0.02
Tridecane	1300	-	-	0.02±0.01	0.04±0.02	0.05±0.01	0.16±0.05
Pentadecane	1499	-	-	-	0.03±0.01	-	0.04±0.01
Phenol (1)		**1.90±0.23**	**3.49±0.49**	**1.22±0.23**	**-**	**3.23±0.66**	**0.09±0.04**
2,4-di-t-Butylphenol	1513	1.90±0.23	3.49±0.49	1.22±0.23	-	3.23±0.66	0.09±0.04
Sulfur (1)		**-**	**-**	**-**	**-**	**-**	**0.03±0.02**
Benzothiophene	1188	-	-	-	-	-	0.03±0.02

LRI: Linear retention indices. N: Normal meat. WS: White Striping myopathy.

Table 3. Profile of volatile compounds (ng/100g) in roasted N and WS chicken breasts at 0, 11 and 14 days of refrigerated storage.

Class/Compound	LRI	N			WS		
		T0	T11	T14	T0	T11	T14
Aldehyde (25)		**479.99±16.22**	**354.84±18.34**	**154.90±19.69**	**1020.15±36,92**	**128.15±4.07**	**68.59±2.95**
Pentanal	<800	12.46±0.42	5.48±0.19	2.98±0.12	35.90±1.27	3.48±0.54	2.74±0.40
Hexanal	800	258.29±24.59	207.07±13.61	47.65±9.68	586.93±29.80	67.75±1.57	31.35±1.81
Heptanal	901	13.19±0.44	10.32±0.35	2.60±0.01	19.04±1.02	3.93±0.47	2.01±0.05
(Z)-2-Heptenal	955	1.44±0.12	0.44±0.02	0.09±0.02	2.68±0.03	0.54±0.01	0.05±0.01
Benzaldehyde	958	6.27±0.29	4.58±0.67	1.22±0.37	8.37±0.75	0.64±0.21	1.01±0.15
Octanal	1003	62.95±3.03	22.20±2.06	85.99±9.15	80.12±0.55	29.76±3.08	21.26±0.52
Benzeneacetaldehyde	1043	0.96±0.06	0.71±0.11	0.10±0.04	1.95±0.14	0.12±0.02	0.11±0.03
(E)-2-Octenal	1057	2.32±0.35	2.05±0.29	0.14±0.04	5.88±0.48	0.72±0.09	0.08±0.02
Nonanal	1105	102.27±6.42	80.01±5.06	13.76±1.19	208.03±8.56	16.86±1.48	8.61±0.48
(Z)-2-Nonenal	1147	-	-	-	0.35±0.09	-	-
3-Ethylbenzaldehyde	1162	1.39±0.22	1.32±0.24	-	3.77±0.13	0.15±0.02	-
(Z)-4-Decen-1-al	1194	0.86±0.03	1.06±0.18	-	3.10±0.04	0.06±0.02	-
Decanal	1205	7.09±0.27	11.09±0.64	-	16.61±0.79	1.41±0.13	0.52±0.07
2,4-Nonadienal	1214	0.41±0.01	0.28±0.01	-	1.94±0.18	0.06±0.02	0.03±0.01

(E)-2-Decenal	1262	1.48±0.20	1.04±0.23	0.36±0.06	5.15±0.04	0.24±0.03	-
Undecanal	1307	0.99±0.02	1.05±0.18	-	2.24±0.18	0.13±0.02	-
2,4-Decadienal	1317	1.02±0.19	1.00±0.40	-	4.57±0.34	-	-
2-Undecenal	1364	1.20±0.02	1.17±0.39	-	6.76±0.45	0.09±0.02	-
2-Butyl-2-octenal	1375	0.33±0.05	-	-	6.79±0.75	1.55±0.23	0.83±0.09
Dodecanal	1409	2.15±0.18	1.58±0.26	-	4.70±0.16	0.26±0.03	-
Pentylbenzaldehyde	1460	-	-	-	0.85±0.11	-	-
Tridecanal	1511	1.20±0.07	1.12±0.25	-	5.01±0.17	0.17±0.02	-
Tetradecanal	1613	1.03±0.12	0.82±0.16	-	4.31±0.28	0.16±0.02	-
Pentadecanal	1715	0.59±0.07	0.41±0.07	-	4.67±0.44	0.08±0.01	-
Hexadecanal	1817	0.10±0.02	0.06±0.01	-	0.43±0.06	-	-
Alcohol (18)		**71.95±2.29**	**87.91±7.37**	**16.26±0.25**	**187.52±9.26**	**21.64±1.92**	**8.35±0.70**
3-Methyl-1-butanol	<800	-	-	-	-	-	0.39±0.05
Pentanol	<800	6.96±0.42	6.01±0.10	8.32±0.50	11.32±0.85	2.64±0.31	1.30±0.13
Hexanol	867	1.80±0.04	2.52±0.23	0.31±0.01	6.77±0.43	0.63±0.05	0.34±0.05
Heptanol	970	4.47±0.19	3.98±0.37	0.85±0.08	9.17±0.46	1.56±0.17	0.50±0.11
1-Octen-3-ol	980	45.14±1.07	60.44±5.65	4.91±0.18	101.56±2.86	13.23±1.44	3.43±0.31
4-Ethylcyclohexanol	998	0.26±0.00	0.36±0.07	0.05±0.01	1.29±0.12	0.12±0.03	0.05±0.00

2-Ethyl-1-hexanol	1030	-	-	0.30±0.03	-	-	1.42±0.08
2,4-Dimethylcyclohexanol	1033	-	-	-	4.87±0.18	-	-
3,5-Ocetadien-2-ol	1039	-	-	-	0.56±0.02	-	-
(Z)-3-Oceten-1-ol	1047	-	0.15±0.02	-	0.79±0.08	-	-
(E)-2-Octen-1-ol	1069	3.03±0.36	3.23±0.63	0.31±0.06	11.51±0.68	0.74±0.09	0.16±0.03
Octanol	1071	8.94±0.12	9.57±1.37	1.21±0.04	27.85±1.94	2.48±0.23	0.76±0.07
1-Nonen-4-ol	1095	0.53±0.03	0.90±0.06	-	5.39±1.11	-	-
2-Nonen-1-ol	1109	-	-	-	0.37±0.08	-	-
Nonanol	1172	0.34±0.02	0.51±0.09	-	1.50±0.13	0.06±0.01	-
Decanol	1266	0.37±0.02	0.25±0.08	-	3.45±0.22	-	-
2-Butyloctanol	1272	-	-	-	0.53±0.01	-	-
Dodecanol	1475	0.11±0.02	-	-	0.59±0.09	0.19±0.04	-
Ketone (6)		**26.52±1.64**	**22.23±2.23**	**0.76±0.04**	**58.70±1.47**	**4.55±0.33**	**1.19±0.19**
2-Heptanone	890	1.59±0.19	1.22±0.24	0.10±0.01	3.66±0.34	0.31±0.01	0.08±0.01
2,5-Octanedione	985	23.11±1.51	20.77±1.93	0.66±0.04	45.23±0.47	4.12±0.30	1.11±0.18
3-Nonanone	1084	-	-	-	0.19±0.04	-	-
3-Undecanone	1283	0.63±0.05	0.14±0.04	-	3.80±0.39	-	-
3-Decen-5-one	1344	0.35±0.05	-	-	1.84±0.06	-	-

3-Dodecanone	1400	0.84±0.05	0.41±0.06	-	3.98±0.17	0.12±0.02	-
Aromatic (1)		**2.00±0.07**	**5.52±0.32**	**6.43±0.44**	**3.16±0.34**	**2.75±0.09**	**3.14±0.44**
Naphthalene	1181	2.00±0.07	5.52±0.32	6.43±0.44	3.16±0.34	2.75±0.09	3.14±0.44
Terpene (3)		**0.31±0.01**	**0.46±0.03**	**0.57±0.11**	**1.00±0.07**	**0.66±0.05**	**0.50±0.05**
o-Cymene	1025	-	-	-	0.28±0.03	0.05±0.00	0.03±0.00
Limonene	1027	0.31±0.01	0.46±0.03	0.57±0.11	0.46±0.02	0.61±0.05	0.47±0.05
D-Verbenone	1217	-	-	-	0.26±0.02	-	-
Furan (2)		**10.74±0.72**	**7.65±0.35**	**0.58±0.10**	**17.94±1.84**	**0.73±0.03**	**0.37±0.05**
2-Pentylfuran	991	10.12±0.69	7.27±0.33	0.50±0.09	15.57±1.66	0.62±0.03	0.32±0.03
2-Octylfuran	1294	0.62±0.04	0.38±0.02	0.08±0.01	2.37±0.18	0.11±0.01	0.05±0.02
Hydrocarbon (5)		**1.28±0.15**	**1.02±0.15**	**-**	**9.74±0.88**	**0.15±0.05**	**0.06±0.00**
Cyclodecane	1140	-	-	-	3.56±0.46	-	-
Dodecane	1199	-	-	-	1.54±0.12	0.05±0.03	0.02±00
Tridecane	1300	1.28±0.15	1.02±0.15	-	3.70±0.25	0.10±0.02	0.04±0.00
1-Pentadecene	1492	-	-	-	0.26±0.02	-	-
Pentadecane	1499	-	-	-	0.68±0.03	-	-
Sulfur (2)		**0.29±0.04**	**0.31±0.07**	**-**	**0.35±0.02**	**0.02±0.01**	**-**
Benzothiophene	1188	0.14±0.03	0.17±0.02	-	0.35±0.02	0.02±0.01	-

Octanethiol	1129	0.15±0.01	0.14±0.05	-	-	-	-
Pyridine (1)		**0.25±0.02**	**0.42±0.15**	**-**	**1.26±0.02**	**-**	**-**
2-Pentylpyridine	1197	0.25±0.02	0.42±0.15	-	1.26±0.02	-	-
Phenol (1)		**0.23±0.05**	**-**	**-**	**-**	**-**	**-**
2,4-di-t-Butylphenol	1513	0.23±0.05	-	-	-	-	-

LRI: Linear retention indices. N: Normal meat. WS: White Striping myopathy.

Table 4. Profile of volatile compounds (ng/100g) in roasted N and WS chicken breasts at 0, 45 and 90 days of frozen storage.

Class/Compound	LRI	N			WS		
		T0	T45	T90	T0	T45	T90
Aldehyde (25)		**479.99±16.22**	**740.57±36.01**	**389.82±7.83**	**1020.15±36.92**	**1028.76±44.08**	**786.07±4.81**
Pentanal	<800	12.46±0.42	25.08±2.18	10.87±0.34	35.90±1.27	25.32±1.47	33.88±0.87
Hexanal	800	258.29±24.59	327.16±7.51	132.11±21.88	586.93±29.80	515.75±40.18	361.43±7.67
Heptanal	901	13.19±0.44	15.70±2.20	8.49±0.37	19.04±1.02	25.40±1.53	15.85±0.17
(Z)-2-Heptenal	955	1.44±0.12	1.48±0.22	1.35±0.16	2.68±0.03	2.71±0.19	2.79±0.06
Benzaldehyde	958	6.27±0.29	9.93±0.37	6.44±0.26	8.37±0.75	9.42±0.86	10.19±0.49
Octanal	1003	62.95±3.03	152.83±37.45	123.70±18.05	80.12±0.55	157.52±7.53	130.53±4.54
Benzeneacetaldehyde	1043	0.96±0.06	0.47±0.04	0.72±0.06	1.95±0.14	1.36±0.05	1.70±0.18
(E)-2-Octenal	1057	2.32±0.35	2.34±0.12	2.10±0.16	5.88±0.48	7.73±0.09	5.14±0.39
Nonanal	1105	102.27±6.42	172.67±8.19	83.83±4.07	208.03±8.56	234.45±10.67	172.08±1.70
(Z)-2-Nonenal	1147	-	-	-	0.35±0.09	-	-
3-Ethylbenzaldehyde	1162	1.39±0.22	1.44±0.39	3.08±0.31	3.77±0.13	5.24±0.41	6.50±0.37
(Z)-4-Decen-1-al	1194	0.86±0.03	0.93±0.03	0.66±0.01	3.10±0.04	1.80±0.40	1.96±0.21
Decanal	1205	7.09±0.27	15.85±0.98	6.52±0.18	16.61±0.79	15.55±1.58	17.49±0.82
2,4-Nonadienal	1214	0.41±0.01	0.59±0.08	0.91±0.09	1.94±0.18	1.63±0.17	1.35±0.11

(E)-2-Decenal	1262	1.48±0.20	0.80±0.05	0.91±0.07	5.15±0.04	2.78±0.07	2.44±0.11
Undecanal	1307	0.99±0.02	1.82±0.19	1.05±0.03	2.24±0.18	2.54±0.02	2.33±0.09
2,4-Decadienal	1317	1.02±0.19	0.22±0.03	0.63±0.07	4.57±0.34	2.24±0.15	2.46±0.37
2-Undecenal	1364	1.20±0.02	0.75±0.08	0.85±0.12	6.76±0.45	3.89±0.12	2.80±0.12
2-Butyl-2-octenal	1375	0.33±0.05	0.50±0.01	0.32±0.03	6.79±0.75	1.85±0.27	2.17±0.50
Dodecanal	1409	2.15±0.18	3.45±0.09	1.96±0.17	4.70±0.16	3.82±0.32	4.07±0.40
Pentylbenzaldeyde	1460	-	-	-	0.85±0.11	0.34±0.03	0.82±0.07
Pentadecanal	1715	0.59±0.07	1.19±0.17	0.62±0.08	4.67±0.44	1.51±0.17	1.37±0.33
Tridecanal	1511	1.20±0.07	2.53±0.01	1.15±0.17	5.01±0.17	3.49±0.09	4.03±0.24
Hexadecanal	1817	0.10±0.02	0.63±0.05	0.27±0.06	0.43±0.06	-	0.19±0.05
Tetradecanal	1613	1.03±0.12	2.21±0.23	1.30±0.07	4.31±0.28	2.44±0.28	2.47±0.42
Alcohol (17)		**71.95±2.29**	**94.05±5.27**	**69.28±4.82**	**187.52±9.26**	**208.31±17.81**	**177.96±5.82**
Pentanol	<800	6.96±0.42	6.02±0.12	6.03±0.51	11.32±0.85	16.23±1.92	11.83±1.29
Hexanol	867	1.80±0.04	4.63±0.35	1.91±0.13	6.77±0.43	8.51±0.42	3.42±0.49
Heptanol	970	4.47±0.19	4.90±0.02	4.34±0.04	9.17±0.46	13.54±2.03	9.22±0.91
1-Octen-3-ol	980	45.14±1.07	57.10±3.07	45.36±3.33	101.56±2.86	113.35±7.61	109.55±0.96
4-Ethylcyclohexanol	998	0.26±0.00	0.23±0.01	0.24±0.02	1.29±0.12	0.88±0.15	1.82±0.08
2-Ethyl-1-hexanol	1030	-	3.59±0.40	-	-	3.78±0.33	-

2,4-Dimenthylcyclohexanol	1033	-	-	-	4.87±0.18	-	4.19±0.45
3,5-Octadien-2-ol	1039	-	-	-	0.56±0.02	0.25±0.03	0.15±0.01
(Z)-3-Octen-1-ol	1047	--	0.37±0.03	0.25±0.03	0.79±0.08	0.56±0.04	0.78±0.04
(E)-2-Octen-1-ol	1069	3.03±0.36	4.01±0.34	0.22±0.10	11.51±0.68	11.30±1.08	9.82±0.55
Octanol	1071	8.94±0.12	11.75±0.67	10.10±0.61	27.85±1.94	32.98±3.26	22.23±0.54
1-Nonen-4-ol	1095	0.53±0.03	0.55±0.11	0.20±0.01	5.39±1.11	3.15±0.16	1.53±0.08
2-Nonen-1-ol	1109	-	-	-	0.37±0.08	1.29±0.30	0.45±0.01
Nonanol	1172	0.34±0.02	0.58±0.11	0.36±0.02	1.50±0.13	1.38±0.39	1.09±0.04
Decanol	1266	0.37±0.02	0.32±0.04	0.27±0.02	3.45±0.22	0.99±0.06	1.65±0.31
2-Butyloctanol	1272	-	-	-	0.53±0.01	0.12±0.03	0.23±0.06
Dodecanol	1475	0.11±0.02	-	-	0.59±0.09	-	-
Ketone (7)		**26.52±1.64**	**43.10±2.40**	**14.63±1.29**	**58.70±1.47**	**52.07±3.94**	**29.11±2.29**
2-Heptanone	890	1.59±0.19	2.82±0.32	1.05±0.06	3.66±0.34	2.02±0.29	2.80±0.03
2,5-Octanedione	985	23.11±1.51	37.40±2.18	12.03±0.98	45.23±0.47	43.92±3.21	21.01±1.60
3-Nonanone	1084	-	-	-	0.19±0.04	-	-
3-Undecanone	1283	0.63±0.05	0.73±0.02	0.30±0.01	3.80±0.39	1.64±0.13	1.25±0.26
Acetophenone	1065	-	0.47±0.04	0.15±0.17	-	1.13±0.01	0.21±0.05
3-Decen-5-one	1344	0.35±0.05	0.71±0.03	0.20±0.03	1.84±0.06	1.17±0.03	1.23±0.29

3-Dodecanone	1400	0.84±0.05	1.44±0.66	0.90±0.04	3.98±0.17	2.19±0.27	2.61±0.06
Hydrocarbon (5)		**1.28±0.15**	**6.86±0.70**	**2.25±0.35**	**9.74±0.88**	**7.96±0.64**	**9.71±0.83**
Cyclodecane	1132	-	0.32±0.06	0.28±0.08	3.56±0.46	1.45±0.11	1.66±0.44
Dodecane	1199	-	1.77±0.26	0.51±0.08	1.54±0.12	1.80±0.07	1.43±0.16
Tridecane	1300	1.28±0.15	4.77±0.38	1.46±0.19	3.70±0.25	3.94±0.30	5.14±0.14
1-Pentadecene	1492	-	-	-	0.26±0.02	0.25±0.11	0.32±0.01
Pentadecane	1499	-	-	-	0.68±0.03	0.52±0.05	1.16±0.08
Furan (2)		**10.74±0.72**	**16.31±1.44**	**5.08±0.77**	**17.94±1.84**	**13.71±0.19**	**9.15±0.67**
2-Pentylfuran	991	10.12±0.69	14.77±1.14	4.25±0.70	15.57±1.66	11.63±0.12	7.73±0.66
2-Octylfuran	1294	0.62±0.04	1.54±0.30	0.83±0.07	2.37±0.18	2.08±0.07	1.42±0.01
Terpene (3)		**0.31±0.01**	**0.60±0.03**	**0.18±0.02**	**1.00±0.07**	**0.99±0.17**	**1.00±0.05**
o-Cymene	1025	-	0.34±0.02	0.18±0.02	0.28±0.03	0.31±0.08	0.61±0.02
Limonene	1027	0.31±0.01	0.26±0.01	-	0.46±0.02	0.33±0.08	-
D-verbenone	1217	-	-	-	0.26±0.02	0.35±0.01	0.40±0.03
Sulfur (2)		**0.29±0.04**	**0.43±0.04**	**0.48±0.06**	**0.35±0.02**	**0.33±0.04**	**0.26±0.05**
Octanethiol	1129	0.14±0.03	-	0.12±0.03	-	-	-
Benzothiophene	1188	0.15±0.01	0.43±0.04	0.36±0.03	0.35±0.02	0.33±0.04	0.26±0.55
Phenol (1)		**0.23±0.05**	**3.40±0.10**	**1.04±0.01**	**-**	**-**	**-**

2,4-di-t-Butylphenol	1513	0.23±0.05	3.40±0.10	1.04±0.01	-	-	-
Pyridine (1)		**0.25±0.02**	**-**	**-**	**1.26±0.02**	**-**	**-**
2-Pentylpyridine	1197	0.25±0.02	-	-	1.26±0.02	-	-
Aromatic (1)		**2.00±0.07**	**5.52±0.32**	**6.43±0.44**	**3.16±0.34**	**2.75±0.09**	**3.14±0.44**
Naphthalene	1181	2.00±0.07	5.52±0.32	6.43±0.44	3.16±0.34	2.75±0.09	3.14±0.44

LRI: Linear retention indices. N: Normal meat. WS: White Striping myopathy.

Table 5. Descriptive sensory odour scores according to the length of storage and myopathy presence in raw and roasted chicken breasts.

Attributes	**RAW**							
	REFRIGERATED				***FROZEN***			
	Time	N	WS	*p*	Time	N	WS	*P*
Sweet aroma	T0	1.97±0.65	nd	-	T0	1.97±0.65	nd	-
	T11	nd	nd	-	T90	$1.65±0.59^{B}$	$2.38±0.68^{A}$	***0.0186***
	p	-	-		*p*	*0.2656*	-	
Fresh chicken	T0	8.83±0.81	8.24±1.31	*0.2411*	T0	$8.83±0.81^{a}$	8.24±1.31	*0.2411*
	T11	8.47±1.55	7.58±1.58	*0.2156*	T90	$4.94±1.01^{bB}$	$8.02±1.01^{A}$	***<0.0001***
	p	*0.5278*	*0.3215*		*p*	***<0.0001***	*0.6858*	
Metallic	T0	1.98±0.94	2.36±0.71	*0.3270*	T0	$1.98±0.94^{a}$	$2.36±0.71^{a}$	*0.3270*
	T11	$1.37±0.36^{B}$	$2.11±0.30^{A}$	***<0.0001***	T90	$0.78±0.55^{b}$	$1.11±0.34^{b}$	*0.0726*
	p	*0.0713*	*0.3215*		*p*	***0.0017***	***<0.0001***	
Other off-odours	T0	nd	nd	-	T0	nd	nd	-
	T11	nd	2.04±0.61	-	T90	nd	nd	-
	p	-	-		*p*	-	-	
Rancid	T0	nd	nd	-	T0	nd	nd	-
	T11	nd	nd	-	T90	$0.42±0.12^{B}$	$1.93±0.54^{A}$	***<0.0001***

	p	-	-		*p*	-	-	
				ROASTED				
Attributes	***REFRIGERATED***				***FROZEN***			
	Time	N	WS	*p*	Time	N	WS	*P*
Sweet aroma	T0	1.14±0.48^{aA}	0.69±0.21^{B}	***0.0150***	T0	1.14±0.48^{bA}	0.69±0.21^{bB}	***0.0150***
	T11	0.60±0.24^{b}	0.57±0.24	*0.7261*	T90	3.81±0.89^{aA}	2.91±0.43^{aB}	***0.0098***
	p	***0.0055***	*0.2290*		*p*	***<0.0001***	***0.0001***	
Cooked chicken	T0	9.63±0.47^{aA}	9.12±0.82^{bB}	***0.0008***	T0	9.63±0.47^{A}	9.12±0.82^{B}	***0.0011***
	T11	7.81±1.59^{b}	9.39±0.84^{a}	*0.1015*	T90	8.82±1.23	8.55±1.30	*0.6399*
	p	***0.0028***	***0.0262***		*p*	*0.0663*	*0.0752*	
Metallic	T0	2.12±0.62^{aA}	1.24±0.33^{B}	***0.0009***	T0	2.12±0.62^{a}	1.24±0.33	*0.5554*
	T11	0.53±0.17^{b}	nd	-	T90	0.58±0.10^{b}	nd	-
	p	***<0.0001***	*0.9018*		*p*	***<0.0001***	-	
Rancid	T0	1.47±0.71	nd	-	T0	1.47±0.71b^{a}	nd	-
	T11	nd	nd	-	T90	0.55±0.20^{bB}	1.49±0.60^{A}	***0.0002***
	p	-	-		*p*	***0.0010***	-	
Fishy	T0	0.83±0.34	nd	-	T0	0.83±0.34^{b}	nd	-
	T11	nd	nd	-	T90	1.62±0.56^{a}	1.82±0.46	*0.3860*

p	-	-	*p*	***0.0013***	-

N: Normal meat. WS: White Striping myopathy.

Nd: not determined.

Different capital letters differ statistically by Tukey’s test. Different lowercase letters differ statistically by Tukey's test.

Capital letters represent the comparative analysis between breast samples. Lowercase letters represent the comparative analysis between storage times.

SUPPLEMENTARY TABLES

Table A. Attributes, description, and intensity scale for sensory analysis.

Attributes	Description	Intensity scale
Fresh chicken	Aroma associated with raw chicken meat	None Strong: Freshly slaughtered raw *white striping* chicken breast
Sweet aroma	Aroma associated with caramelized sugar	None Strong: Aqueous sugar solution (1:2 - sugar:water)
Rancid	Characteristic odour intensity of oxidized fat	None Strong: soybean oil used in the frying process repeatedly times
Fishy	Aroma associated with fried fish	None Forte: Skinless fried tilapia
Metallic	Aroma associated with metals, tin or iron	None Strong: 1% ferrous sulphate solution
Other off-odours	The uncharacteristic odour of chicken, such as fermented odour	None Strong: Raw chicken breast 24h after the slaughter and stored at room temperature
Cooked chicken	Aroma associated with cooked chicken meat	None

	Strong: Cooked *white striping* chicken breast

Table B. Volatile classes of raw WS and N chicken breast submitted to refrigeration and freezing storage.

Volatile class	Chicken breast	CHILLED				FROZEN			
		0	**11**	**14**		**0**	**45**	**90**	
Total number	N	21	29	25		21	23	30	
	WS	38	40	30		38	38	50	
Total concentration	N	78.43±6.05	99.16±4.72	60.20±6.89		78.43±6.05	137.06±6.72	67.61±3.80	
	WS	100.18±7.62	52.77±2.19	49.67±3.78		100.18±7.62	144.47±14.57	141.65±16.12	
Alcohol	N	$5.56±0.74^{cB}$	$15.90±0.26^{aA}$	$7.80±0.38^{bA}$	***<0.0001***	$5.56±0.74^{bB}$	$6.08±0.14^{bB}$	$9.18±0.68^{aB}$	***0,0003***
	WS	$20.47±1.81^{xA}$	$8.05±0.49^{yB}$	$7.04±0.48^{yA}$	***<0.0001***	$20.47±1.81^{yA}$	$26.29±4.81^{yA}$	$39.10±3.41^{xA}$	***0,0012***
	p	***0,0002***	***<0.0001***	*0,0992*		***0,0002***	***0,0011***	***0,0001***	
Aldehyde	N	$68.79±4.83^{bA}$	$79.88±3.98^{aA}$	$44.46±5.54^{cA}$	***0,0002***	$68.79±4.83^{bA}$	$124.82±5.94^{aA}$	$55.49±2.81^{cB}$	***<0.0001***
	WS	$75.49±5.22^{xA}$	$38.60±0.82^{yB}$	$34.45±1.30^{yB}$	***<0.0001***	$75.49±5.22^{yA}$	$110.57±8.70^{xB}$	$95.37±11.58^{xA}$	***0,0025***
	p	*0,1361*	***<0.0001***	***0,0382***		*0,1361*	***0,0479***	***0,0019***	
Aromatic	N	nd	nd	$6.92±0.85^{A}$	-	nd	$0.90±0.01^{B}$	$0.09±0.02^{B}$	-
	WS	$0.63±0.06^{z}$	$3.82±0.35^{y}$	$7.14±1.78^{xA}$	***0,0008***	$0.63±0.06^{y}$	$1.03±0.06^{xA}$	$0.22±0.04^{zA}$	***<0.0001***
	p	-	-	*0,8530*		-	***0,0164***	***0,0067***	
Ester	N	nd	$0.09±0.03^{A}$	nd	-	nd	nd	nd	-

	WS	0.04±0.01	0.03±0.01^{B}	nd	-	0.04±0.01^{y}	0.04±0.01^{y}	0.11±0.02^{x}	***0,0005***
	p	-	***0,0174***	-		-	-	-	
Furan	N	0.10±0.04^{bB}	0.31±0.05^{aA}	0.10±0.04^{bA}	***0,0009***	0.10±0.04^{bB}	0.42±0.04^{aA}	0.17±0.02^{bB}	***<0.0001***
	WS	0.62±0.06^{xA}	0.22±0.03^{yB}	0.11±0.02^{zA}	***<0.0001***	0.62±0.06^{yA}	0.49±0.10^{yA}	0.93±0.18^{xA}	***0,0109***
	p	***<0.0001***	***0,0282***	*0,7383*		***<0.0001***	*0,2994*	***0,0019***	
Hydrocarbon	N	nd	0.05±0.01^{A}	nd	-	nd	nd	0.02±0.01^{B}	-
	WS	0.10±0.03	0.03±0.01^{B}	nd	-	0.10±0.03^{y}	0.07±0.02^{y}	0.26±0.05^{xA}	***0,0013***
	p	-	***0,0154***	-		-	-	***0,0016***	
Ketone	N	1.50±0.15^{aB}	1.21±0.13^{bA}	0.48±0.02^{cA}	*<0.0001*	1.50±0.15^{aB}	1.35±0.10^{aB}	1.25±0.33^{aB}	*0,0686*
	WS	2.35±0.33^{xA}	0.99±0.12^{yA}	0.50±0.13^{yA}	*0,0001*	2.35±0.33^{yA}	2.45±0.13^{yA}	5.45±0.76^{xA}	***0,0002***
	p	***0,0143***	*0,0885*	*0,7882*		***0,0143***	***0,0003***	***0,0003***	
Phenol	N	1.90±0.23^{a}	1.27±0.25^{bA}	0.04±0.00^{c}	*<0.0001*	1.90±0.23^{b}	3.49±0.49^{aA}	1.22±0.23^{bA}	***0,0005***
	WS	nd	0.45±0.27^{B}	nd	-	nd	3.23±0.66^{A}	0.09±0.04^{B}	-
	p	-	***0,0187***	-		-	*0,6186*	***0,0011***	
Sulfur	N	nd	nd	0.04±0.00^{A}	-	nd	nd	nd	-
	WS	nd	0.03±0.01	0.05±0.00^{A}	-	nd	nd	0.03±0.02	-
	p	-	-	*0,0973*		-	-	-	
Terpene	N	0.58±0.06^{aA}	0.45±0.01^{bA}	0.36±0.06^{cA}	***0,0006***	0.58±0.06^{A}	nd	nd	-

	WS	0.48±0.11^{xA}	0.55±0.08^{xA}	0.38±0.07^{xA}	*0,1135*	0.48±0.11^{A}	0.32±0.08	nd	-
	p	*0,1822*	*0,0825*	*0,7557*		*0,1822*	-	-	

N: Normal meat. WS: White Striping myopathy.

Nd: not determined.

Different capital letters differ statistically by t-Student's test. Different lowercase letters differ statistically by Tukey's test.

Capital letters represent the comparative analysis between breasts. Lowercase letters represent the comparative analysis between storage times.

4. CONCLUSÕES GERAIS

Os filés de peito Normais e *White Striping*, ao serem armazenados sob refrigeração, apresentam níveis de umidade e teor de proteínas semelhantes e o efeito de preservação na oxidação lipídica e proteica em ambos os filés. Contudo, foi observado divergências notáveis quanto ao teor de lipídios, pH, força de cisalhamento e parâmetros de cor. Quando armazenados sobre congelamento houve redução significativa no pH e na força de cisalhamento, bem como elevados níveis de oxidação lipídica e proteica, que ocasionam características desagradáveis e perceptíveis.

Pode-se entender que o efeito do armazenamento refrigerado e congelado em filés de peito de frango N e WS, crus e assados, apresentam resultados semelhantes quanto as características nutricionais, havendo apenas uma leve redução no odor de frango fresco da carne WS crua. Percebe-se, então, que a refrigeração se mostra como mais eficiente para reduzir os danos oxidativos nos primeiros 11 dias de armazenamento.

As análises do perfil volátil dos filés de peito de frango, demonstraram que os compostos que tiveram maior contribuição foram os aldeídos, independentemente do tipo de filé analisado e condição de armazenamento. Contudo, para os filés de peito crus N e WS, notou-se predomínio do Octanal conferindo uma característica de aroma verde e cítrico, enquanto os filés de peito assados N e WS tiveram maior contribuição o composto Hexanal com perfil de odor verde e gorduroso.

Filés de peito de frango analisados sensorialmente demonstraram que sob condições de estocagem refrigerada ou congelada os avaliadores perceberam um maior odor característico de frango fresco para ambos os filés de peito N e WS cruas e de frango cozido para os filés N e WS assados.

Para futuras pesquisas, é sugerido que seja avaliado os possíveis danos provocados pelas oxidações lipídicas e proteicas, estocados ao frio, em filés de peito de frango acometidos pela miopatia WS em vários ciclos de armazenamento a longo prazo. Atrelado a isso, sugere-se que análises sensoriais sejam realizadas, de modo que possam demonstrar a aceitação de filés de frango acometidos pela miopatia WS estocados em períodos prolongados.

APÊNDICES

APÊNDICE A – Termo de Consentimento Livre e Esclarecido - TCLE

Termo de Consentimento Livre e Esclarecido

Título da pesquisa: "EFEITO DO RESFRIAMENTO E CONGELAMENTO NO PERFIL DE VOLÁTEIS E SENSORIAL DE PEITOS DE FRANGO ESTRIADO '*White Striping*'.

Prezado(a) Senhor(a):

Gostariamos de convidá-lo a participar da pesquisa "Efeito do resfriamento e congelamento no perfil de voláteis e sensorial de peitos de frango estriado '*White Striping'*, realizada na **Universidade Federal da Paraíba**. O ojetivo da pesquisa é avaliar o efeito do armazenamento resfrigerado durante 0, 11 e 14 dias e congelado durante 0, 45 e 90 dias, no perfil de voláteis e sensorial. A sua participação é muito importante e, se daria através de uma análise sensorial e o preenchimento do quetionário em relação ao alimento avaliado. Gostaríamos de esclarecer que sua participação é totalmente voluntária, podendo você recusar-se a paticipar, ou mesmo desistir a qualquer momento sem que isto acarrete qualquer ônus ou prejuízo à sua pessoa. Informamos também que as informações serão utilizadas somente para fins desta pesquisa e serão tratadas com o mais absoluto sigilo e confidencialidade, de modo a preservar a sua identidade.

Os benefícios esperados são: identificar se o aroma de peitos de frango White Striping comparados a peitos de frango Normais, sofrem interferências pelo acondicionamento refrigeração ou congelamento. Informos que o (a) senhor (a) não pagará nem será remunerado por sua participação. Caso o (a) senhor (a) tenha dúvidas ou necessite de maiores esclarecimentos pode nos contactar:

Pesquisador responsável:

Djalma Vitorino Costa Filho, Rua Comerciante Augusto Luiz do Carmo, 209 – Bairro: Cajá, Vitória de Santo Antão – PE. CEP: 55.610-078. Telefone: (081) 987745559. E-mail: djalmavitorinocostafilho@gmail.com

Ou procurar o Comitê de Ética em Pesquisa da Universidade Federal da Paraíba, localizado no Centro de Ciências da Saúde - 1º andar, Campus I - Cidade Universitária. CEP: 58.051-900 - João Pessoa-PB. Telefone: (83) 3216 7791, e-mail: eticaccsufpb@hotmail.com. Este termo deverá ser preenchido em duas vias de igual teor, sendo uma delas, devidamente preenchida, assinada e entregue ao(a) senhor(a). Diante do exposto, declaro que fui devidamente esclarecido(a) e dou o meu consentimento para participar da pesquisa e para publicação dos resultados.

_____ _____

Assinatura do Participante da Pesquisa Assinatrua da Testemunha

Atenciosamente,

_____

Assinatura do pesquisador responsável

João Pessoa – PB, __ de _____ de _____.

*Termo de Consentimento Livre Esclarecido apresentado, atendendo, conforme normas da Resolução 466/2012 de 12 de dezembro de 2012.

APÊNDICE B – Ficha de avaliação sensorial: Análise Descritiva Quantitativa - ADQ

ANÁLISE DESCRITIVA QUANTITATIVA

Nome:_____ **Data:**_____

Por favor, CHEIRE as amostras codificadas da esquerda para direita e avalie a intensidade das notas aromáticas presente em cada uma das amostras. **Instruções**: Faça um traço vertical na linha horizontal que melhor descreva cada atributo.

AROMA

Doce
Nenhum Moderado Forte

Frango fresco/cru
Nenhum Moderado Forte

Frango cozido
Nenhum Moderado Forte

Metálico
Nenhum Moderado Forte

Estranho
Nenhum Moderado Forte

Rançoso
Nenhum Moderado Forte

Peixe
Nenhum Moderado Forte

Tabela com os atributos, descritores e escala de intensidade

Atributos	**Descrição**	**Escala**
Frango cru	Aroma associado com músculo de frango cru	Nada Forte: Peito de frango White striping cru recém abatido
Aroma Doce	Aroma associado a açúcar caramelizado	Nada Forte: Solução de açúcar e água 1:2
Rançoso	Intensidade de odor característico de gordura oxidada, odor forte	Nada Forte: óleo de soja utilizado em processo de fritura e requentado
Aroma de peixe	Aroma associado a carne de peixe frito	Nada Forte: Peixe tilápia frito sem pele
Metálico	Aroma associado a metais, estanho ou ferro	Nada Forte: Solução de sulfato ferroso a 1%
Estranho	Odor não característico de frango, alterado, fermentado	Nada Forte: Peito de frango cru 24h após o abate a temperatura ambiente
Frango cozido	Aroma associado com músculo de frango cozido	Nada Forte: Peito de Frango White striping cozido

ANEXOS

ANEXO A – Parecer Consubstanciado do CEP.

UFPB - CENTRO DE CIÊNCIAS DA SAÚDE DA UNIVERSIDADE FEDERAL DA PARAÍBA

PARECER CONSUBSTANCIADO DO CEP

DADOS DO PROJETO DE PESQUISA

Título da Pesquisa: Qualidade de Peitos de Frango e Processados Cárneos Elaborados com Peitos de Frango "Wooden" e "White Striping"

Pesquisador: Leila Moreira de Carvalho

Área Temática:

Versão: 3

CAAE: 67651917.4.0000.5188

Instituição Proponente: Programa de pós-graduação em ciência e tecnologia de alimentos

Patrocinador Principal: Financiamento Próprio

DADOS DO PARECER

Número do Parecer: 2.545.797

Apresentação do Projeto:

Projetos das discentes Leila Moreira de Carvalho, nível doutorado e Thayse Cavalcanti da Rocha, nível mestrado, orientação da profª Marta S. Madruga do programa PPGCTA/CT/UFPB.

Objetivo da Pesquisa:

Avaliar as características físico-químicas, químicas e sensoriais de linguiça frescal de frango elaborados a partir de carne "Wooden Breast", ao longo do armazenamento.

Avaliação dos Riscos e Benefícios:

Riscos potenciais previsíveis e evitáveis.

Benefícios:

Esse trabalho irá contribuir significativamente para a valorização dos derivados da cadeia produtiva de aves.

Comentários e Considerações sobre a Pesquisa:

Em consonância com os objetivos, referencial teórico, metodologia e referências.

Considerações sobre os Termos de apresentação obrigatória:

Apresenta todos os termos necessários.

Recomendações:

Atualizar o cronograma, para que possa transcorrer o desenvolvimento em concordância com a Resolução 466/2012.

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UF: PB **Município:** JOAO PESSOA
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Continuação do Parecer: 2.545.797

Conclusões ou Pendências e Lista de Inadequações:

Favorável ao desenvolvimento da pesquisa, desde que atenda a recomendação.

Considerações Finais a critério do CEP:

Certifico que o Comitê de Ética em Pesquisa do Centro de Ciências da Saúde da Universidade Federal da Paraíba – CEP/CCS aprovou a execução do referido projeto de pesquisa.

Outrossim, informo que a autorização para posterior publicação fica condicionada à submissão do Relatório Final na Plataforma Brasil, via Notificação, para fins de apreciação e aprovação por este egrégio Comitê.

Este parecer foi elaborado baseado nos documentos abaixo relacionados:

Tipo Documento	Arquivo	Postagem	Autor	Situação
Informações Básicas do Projeto	PB_INFORMAÇÕES_BÁSICAS_DO_PROJETO_891743.pdf	23/10/2017 10:58:22		Aceito
Projeto Detalhado / Brochura Investigador	ProjetoWB.pdf	23/10/2017 10:57:36	Leila Moreira de Carvalho	Aceito
Orçamento	Orcamento.pdf	23/10/2017 10:54:10	Leila Moreira de Carvalho	Aceito
Cronograma	CronogramaDetalhado.pdf	23/10/2017 10:53:25	Leila Moreira de Carvalho	Aceito
TCLE / Termos de Assentimento / Justificativa de Ausência	TCLE.pdf	23/10/2017 10:52:13	Leila Moreira de Carvalho	Aceito
Outros	Termo_de_doacao.pdf	25/04/2017 08:45:53	Leila Moreira de Carvalho	Aceito
Folha de Rosto	Folha_de_rosto.pdf	24/04/2017 11:42:05	Leila Moreira de Carvalho	Aceito
Declaração de Instituição e Infraestrutura	CartaAnuencia.pdf	08/04/2017 21:41:36	Leila Moreira de Carvalho	Aceito
Outros	InstrumentoDeColeta.pdf	08/04/2017 21:39:40	Leila Moreira de Carvalho	Aceito
Outros	DeclaracaoAprovacaoProjeto.jpg	08/04/2017 21:39:05	Leila Moreira de Carvalho	Aceito

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Situação do Parecer:
Aprovado

Necessita Apreciação da CONEP:
Não

JOAO PESSOA, 15 de Março de 2018

Assinado por:
Eliane Marques Duarte de Sousa
(Coordenador)

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ANEXO B – Comprovante submissão de manuscrito

LWT

Effect of refrigeration and freezing on the sensory profile and volatile compounds of white striping chicken breast

--Manuscript Draft--

Manuscript Number:	
Article Type:	Research paper
Keywords:	aroma; cold storage; poultry; myopathies; shelf-life
Corresponding Author:	Marta Madruga, Dr Federal University of Paraiba João Pessoa, BRAZIL
First Author:	Djalma Vitorino Costa Filho
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	Leila Moreira de Carvalho
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	Lary Souza Olegario
	Viviane Maria de Sousa Fontes
	Jéssica Moreira de Carvalho
	Mércia de Sousa Galvão
	Taliana Kênia Bezerra
	Mario Estévez
	Marta Madruga, Dr
Abstract:	This study aimed to investigate the chemical and sensory aromatic quality of broiler breast with severe White Striping ([WS], white stripes >1 mm thickness) disorder when refrigerated and frozen. The number and concentration of volatile compounds in cold storage were higher in raw WS compared to raw normal (N) meat. The primary volatile compounds found were aldehydes, regardless of breast type and temperature storage condition. The number and concentration of volatile compounds in raw and roasted WS were higher when compared to N breasts at the beginning of the storage period (t=0 days). Throughout frozen storage, panellists noted the appearance of "sweet" and "rancid" aroma and a decrease in "metallic" aroma in raw WS breast. While the roasted WS breasts showed an increase in "sweet" aroma, and the appearance of "rancid" aromas, and "fish". The aromatic profile of raw and roasted broiler breasts is influenced not only by the occurrence of myopathy (WS) but also by the type of storage (refrigerated or frozen).
Suggested Reviewers:	Eero Puolanne eero.puolanne@helsinki.fi Eero Puolanne is a renowned researcher who works in research involving poultry meat and myopathies.
	Massimiliano Petracci m.petracci@unibo.it He is a researcher whose contribution to the study of the mechanisms and characterization of growth-related meat abnormalities in birds such as white streaks is recognized worldwide. His research encompasses from aspects of poultry production to product quality.
	Francesca Soglia francesca.soglia2@unibo.it She is involved in various research projects that study poltry meat and myopathies.