DANIELE JULIANA RODRIGUES GONÇALVES

EFEITO DO ULTRASSOM NA CINÉTICA DE SECAGEM DE GOIABA POTENCIALMENTE PROBIÓTICA (*Psidium guajava*), VIABILIDADE DE *Lacticaseibacillus rhamnosus* GG E QUALIDADE FUNCIONAL

Dissertação apresentada à Universidade Federal de Viçosa, como parte das exigências do Programa de Pós-Graduação em Ciência e Tecnologia de Alimentos, para obtenção do título de *Magister Scientiae*.

Orientador: Bruno Ricardo de Castro Leite Junior

Coorientadoras: Érica Nascif Rufino Vieira
Eliane Maurício Furtado Martins

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Bruno Ricardo de Castro Leite Junior
Orientador

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RESUMO

GONÇALVES, Daniele Juliana Rodrigues, M.Sc, Universidade Federal de Viçosa, maio de 2023. **Efeito do ultrassom na cinética de secagem de goiaba potencialmente probiótica (*Psidium guajava*), viabilidade de *Lacticaseibacillus rhamnosus* GG e qualidade funcional.** Orientador: Bruno Ricardo de Castro Leite Júnior. Coorientadoras: Érica Nascif Rufino Vieira e Eliane Maurício Furtado Martins.

Estudos recentes mostram o impacto positivo do pré-tratamento ultrassônico (US) na redução do tempo de secagem de frutas e vegetais e na adaptação de probióticos em matrizes vegetais. No entanto, não há estudos na literatura que avaliaram o efeito do pré-tratamento por US em goiaba adicionada de *Lacticaseibacillus rhamnosus* GG visando otimizar o tempo de secagem e manter a viabilidade do probiótico no produto desidratado. Assim, este estudo avaliou o impacto do US na cinética de secagem de goiaba potencialmente probiótica, na viabilidade de *L. rhamnosus* GG e na qualidade funcional do produto durante a secagem. Fatias de goiaba foram pré-tratadas por US (38 W/L, 25 kHz) por 15 e 30 minutos, posteriormente foram imersas por 15 ou 30 minutos em solução contendo *L. rhamnosus* GG assistido ou não por US. Foram realizados 9 tratamentos combinando o pré-tratamento com ultrassom (US) e adição da cultura probiótica (T1 - amostra sem pré-tratamento ultrassônico e sem adição de *L. rhamnosus* GG; T2 - amostra pré-tratada por US por 15 min sem adição de *L. rhamnosus* GG; T3 - amostra pré-tratada por US por 30 min sem adição de *L. rhamnosus* GG; T4 - amostra sem pré-tratamento ultrassônico imersa em solução de *L. rhamnosus* GG por 15 min; T5 - amostra pré-tratada por US por 15 min e imersa em solução de *L. rhamnosus* GG por 15 min; T6 - amostra imersa em solução de *L. rhamnosus* GG por 15 min assistida por US; T7 - amostra sem pré-tratamento ultrassônico imersa em solução de *L. rhamnosus* GG por 30 min; T8 - amostra pré-tratada por US por 30 min e imersa em solução de *L. rhamnosus* GG por 30 min; T9 - amostra imersa em solução de *L. rhamnosus* GG por 30 min com auxílio de US). Após os pré-tratamentos, as amostras foram submetidas à secagem convectiva a 60 °C até as amostras apresentarem 25% de umidade. O pré-tratamento US melhorou a taxa de secagem (até 59 %) e reduziu o tempo de secagem (até 31 %) em comparação com amostras não sonicadas. A redução no tempo de secagem (de ~6 horas para ~4 horas para amostras processadas por US) foi crucial para manter a viabilidade do probiótico nas goiabas desidratadas. Essas amostras T8 e T9 apresentaram contagens de 6,15 a 7,00 UFC.g^{-1} após 4 horas, enquanto as amostras controles requereram 6 horas de secagem e atingiram contagens de 4,17 a 4,45 UFC.g^{-1}. O pré-tratamento US não

afetou os parâmetros de cor das amostras antes da secagem ($p > 0,05$) e ambas as amostras tiveram comportamento similar durante a secagem em relação a cor. Os compostos funcionais foram reduzidos durante a secagem ($p < 0,05$), no entanto, as amostras pré-tratadas por US apresentaram menores reduções no teor de vitamina C (até 20 %), compostos fenólicos (até 41 %) e capacidade antioxidante (até 47 %) em comparação com amostras de controle (até 52%, 81% e 61%, respectivamente). Assim, o pré-tratamento US reduziu o tempo de secagem das fatias de goiaba e minimizou o impacto negativo do tratamento térmico na viabilidade probiótica e nos compostos funcionais, sendo considerado uma estratégia promissora para produzir goiaba desidratada potencialmente probiótica.

Palavras-chave: Cinética de secagem. Tecnologias emergentes. Compostos funcionais. Frutas e vegetais. Alimentos probióticos. Tecnologia de ultrassom.

ABSTRACT

GONÇALVES, Daniele Juliana Rodrigues, M.Sc, Universidade Federal de Viçosa, May 2023. **Effect of ultrasound on drying kinetics of potentially probiotic guava (Psidium guajava), viability of *Lacticaseibacillus rhamnosus* GG and functional quality.** Advisor: Bruno Ricardo de Castro Leite Júnior. Co-Advisors: Érica Nascif Rufino Vieira and Eliane Maurício Furtado Martins.

Recent studies show the positive impact of ultrasonic pretreatment (US) in reducing the drying time of fruits and vegetables and in the adaptation of probiotics in plant matrices. However, there are no studies in the literature that evaluated the effect of pretreatment by US in guava added with *Lacticaseibacillus rhamnosus* GG to optimize the drying time and maintain the viability of the probiotic in the dehydrated product. Thus, this study evaluated the impact of US on the drying kinetics of potentially probiotic guava, on the viability of *L. rhamnosus* GG and on the functional quality of the product during drying. Guava slices were pre-treated by US (38 W/L, 25 kHz) for 15 and 30 minutes, then immersed for 15 or 30 minutes in a solution containing L. rhamnosus in a GG process, assisted or not by US. Nine treatments were performed combining pre-treatment with ultrasound (US) and addition of probiotic (T1 - sample without ultrasonic pre-treatment and without addition of *L. rhamnosus* GG; T2 - sample pre-treated by US for 15 min without addition of *L. rhamnosus* GG; T3 - sample pre-treated by US for 30 min without addition of *L. rhamnosus* GG; T4 - sample without ultrasonic pretreatment immersed in *L. rhamnosus* GG solution for 15 min; T5 - sample pre-treated by US for 15 min and immersed in *L. rhamnosus* GG solution for 15 min; T6 - US-assisted sample immersed in *L. rhamnosus* GG solution for 15 min; T7 - sample without ultrasonic pretreatment immersed in *L. rhamnosus* GG solution for 30 min; T8 - sample pre-treated by US for 30 min and immersed in *L. rhamnosus* GG solution for 30 min; T9 - sample immersed in *L. rhamnosus* GG solution for 30 min with the aid of US). After the pre-treatments, the samples were subjected to convective drying at 60 °C until the samples had 25% moisture. US pretreatment improved drying rate (up to 59%) and tracked dehydration time (up to 31%) compared to non-sonicated samples. The reduction in drying time (from ~6 hours to ~4 hours for samples processed by US) was crucial to maintain the viability of the probiotic in the dried guavas. These T8 and T9 samples showed counts of 6.15 to 7.00 CFU.g-1 after 4 hours, while the control samples required 6 hours of drying and reached counts of 4.17 to 4.45 CFU.g-1 . The US pre-treatment did not affect the color parameters of the samples before drying ($p > 0.05$) and both samples

showed similar behavior during drying in terms of color. Compound compounds were reduced during drying ($p<0.05$), however, as the sample pre-treated by US showed smaller reductions in vitamin C content (up to 20%), phenolic compounds (up to 41%) and capacity antioxidant (up to 47%) compared to Control Exceptions (up to 52%, 81% and 61% respectively). Thus, the US pretreatment included drying time of guava slices and minimized the negative impact of heat treatment on probiotic viability and compounds, being considered a promising strategy to produce potentially probiotic dehydrated guava.

Keywords: Drying kinetics. Emerging technologies. Functional compounds. Fruits and vegetables. Probiotic foods. Ultrasound technology.

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INTRODUÇÃO GERAL

As frutas são amplamente apreciadas e têm grande importância na dieta da população. No entanto, o consumo desses alimentos é afetado pelo alto grau de perecibilidade. Assim, devido aos períodos de sazonalidade e perecibilidade, torna-se necessária a aplicação de tecnologias que possam fornecer um melhor aproveitamento dessas matérias-primas.

O Brasil se destaca na produção mundial de goiaba (*Psidium guajava L.*), esta fruta tropical é bastante apreciada por seu aroma, sabor e cor característicos, além de possuir elevado valor nutritivo e propriedades funcionais. Para fins comerciais, a goiaba é processada na forma de polpa, sucos, néctares, geleias e concentrados (GALLI *et al*., 2019; ARANGO *et al*., 2020).

Dentre as diversas frutas com potencial funcional, a goiaba *(Psidium guajava L.)* apresenta-se como excelente fonte de vitaminas (vitaminas A, C e E), compostos fenólicos, antocianinas, minerais (cálcio e selênio) e fitoesteróis. Essa fruta pode ser consumida *in natura*, entretanto, devido à alta perecibilidade, pode ser submetida ao processamento para produção de geleias, compotas, conservas ou sucos. Além disso, uma alternativa que vem sendo aplicada desde a antiguidade para a conservação dos alimentos é a secagem, uma prática que consiste em prolongar a estabilidade de um alimento por meio de remoção de parte de sua água, aumentando seu tempo de prateleira.

A secagem convectiva convencional apresenta algumas limitações como por exemplo: longo tempo de processo, baixa produtividade, alto consumo de energia, temperaturas elevadas, dentre outros fatores que impactam diretamente na qualidade nutricional e sensorial do alimento. Isso pode resultar, em perdas nutricionais e alterações indesejáveis nas características de cor, aroma, sabor e aparência do produto. Desta forma, a aplicação de tecnologias não - convencionais no pré-processamento vegetal é uma estratégia inovadora para superar essas limitações. Neste contexto, o ultrassom (US) tem sido usado antes da secagem de frutas e hortaliças visando a redução nos tempos de secagem de processo, pois a aplicação de ultrassom pode produzir um aumento na difusividade efetiva da água e no coeficiente de transferência de massa, alterando a cinética de secagem e acelerando este processo. Ainda, a redução do tempo de secagem dos vegetais pré-tratados por ultrassom pode minimizar as perdas nutricionais desses alimentos, resultando em produtos com melhor qualidade, custo e rendimento (FAN; ZHANG; MUJUMDAR, 2017).

Considerando que os consumidores estão cada vez mais preocupados com a saúde e o bem-estar, e, por isso, buscam alimentos que possam trazer benefícios funcionais ao organismo (AGUIAR et al., 2019), os alimentos probióticos têm se destacado como uma opção saudável e funcional. Normalmente, microrganismos probióticos são usados em produtos de laticínios,

mas apresentam grande potencial de aplicação em produtos de origem vegetal (LEITE et al., 2018; GALLINA et al., 2019; ROLIM et al., 2020; KIM et al., 2020; ZENDEBOODI et al., 2020; ZHOU et al., 2020).

Os produtos lácteos fermentados geralmente fornecem boas matrizes transportadoras de micro-organismos probióticos. No entanto, outras matrizes alimentares também têm sido estudadas como potenciais carreadoras desses microrganismos. O número crescente de indivíduos com intolerância à lactose, dislipidemia e vegetarianismo reforça a importância do desenvolvimento de produtos probióticos não lácteos, como frutas e vegetais (PERES et al., 2012, RANADHEERA et al., 2010).

Embora estudos recentes avaliem positivamente o impacto do pré-processamento por US na redução do tempo de secagem de frutas e hortaliças e adaptação de probióticos em matrizes vegetais, são escassos na literatura trabalhos que avaliem o efeito do pré-processamento por US em goiaba potencialmente probiótica visando a otimização do tempo de secagem e a melhoria da qualidade do produto final, lacuna esta preenchida pela realização deste trabalho.

OBJETIVOS

Objetivo Geral

Avaliar o impacto do pré-tratamento por ultrassom no efeito da cinética de secagem de goiaba *(Psidium guajava L.)* adicionada de *Lacticaseibacillus rhamnosus* GG avaliar a **viabilidade de *Lacticaseibacillus rhamnosus* GG e qualidade funcional**

Objetivo Específicos

- Avaliar o impacto dos pré-tratamentos ultrassônicos na cinética de secagem a 60 °C de goiaba adicionada de *Lacticaseibacillus rhamnosus* GG.
- Avaliar o impacto dos pré-tratamentos ultrassônicos na viabilidade de *Lacticaseibacillus rhamnosus* GG em goiaba durante a secagem à 60 °C.
- Avaliar o impacto dos pré-tratamentos ultrassônicos na cor, no teor de Vitamina C e compostos fenólicos totais e na atividade antioxidante *in vitro* de goiaba adicionada de *Lacticaseibacillus rhamnosus* GG durante a secagem à 60 °C.

CAPÍTULO 1

REFERENCIAL TEÓRICO

1. Goiaba vermelha (*Psidium guajava L.*): Origem e qualidade nutricional

A goiabeira (*Psidium guajava L.)* pertence à família Myrtaceae originária da América Central e do Sul, é uma cultura muito resistente, que tolera altas temperaturas e clima seco, principalmente na região do semiárido (FORATO et al., 2015). A goiabeira produz frutos doces e saborosos com interessante qualidade nutricional, preço acessível e de fácil comercialização, tendo uma boa aceitação dos consumidores (NIMISHA et al., 2013). A Tabela 1 apresenta a composição química da goiaba em uma porção de 100g.

Tabela 1 - Composição química da goiaba em porção de 100g.

Composição Química	Quantidade
Calorias	69 kcal
Água	80,6g
Hidratos de Carbono	17,3g
Proteínas	1g
Lipídios	0,50g
Cinzas	0,7g
Cálcio	15mg
Fósforo	24mg
Ferro	0,7mg
Sódio	4mg
Potássio	291mg
Caroteno	75µg
Riboflavina	0,04mg
Ácido ascórbico	132mg

Fonte: (HORTO DIDÁTICO DE PLANTAS MEDICINAIS DO HU, 2018)

Essa fruta apresenta uma produção satisfatória. Durante todo o ano, sendo bastante popular devido à sua alta disponibilidade. A Figura 1 ilustra a goiaba vermelha *(Psidium guajava L.)* em dois momentos, mostrando a parte interna e por inteiro com casca.

Figura 1. Goiaba Vermelha *(Psidium guajava L.)*

Fonte: (S. PACHECO, 2023).

Embora seja comumente consumida fresca, a goiaba tem elevada taxa respiratória e amadurece rapidamente, o que resulta em baixa vida de prateleira durante o armazenamento em temperatura ambiente (HONG et al., 2012; VISHWASRAO; ANANTHANARAYAN, 2016).

Desta forma, estrategicamente, pode ser realizado o processamento da goiaba visando a produção de derivados, como bebidas, sorvetes, geleias e doces, representando cerca de 53 % de toda a produção de goiaba (DEL'ARCO; SYLOS, 2018). Além disso, tem sido relatado que cerca de 30 % dos coprodutos da goiaba (sementes, casca e sobras de polpa) são descartados durante seu processamento, apesar de sua composição rica em bioativos (MILANI et al., 2017).

Outra estratégia empregada, é o processamento mínimo de goiaba, com embalagens ativas utilizando filmes e revestimentos comestíveis para aumentar a vida útil deste vegetal (MOSTAFIDI et al., 2020). Outra alternativa de processamento é a secagem das goiabas constituindo oportunidade interessante para prolongar sua vida útil. No próximo tópico essa temática será discutida em mais detalhes.

2. Secagem de vegetais

A secagem é um processo que consiste na eliminação de água de um produto por evaporação, com transferência de calor e massa. A secagem por convecção é o método de preservação mais conhecido devido ao seu baixo custo (CHUA & CHOU, 2003)

Segundo a Resolução de Diretoria Colegiada (RDC) n° 272 (BRASIL, 2005), fruta seca é o produto obtido pela perda parcial da água da fruta madura, inteira ou em pedaços, por processos tecnológicos adequados que possibilitem a manutenção de, no máximo, 25 % de umidade (g/100 g).

Durante a secagem, é na superfície do material que ocorre a evaporação da água, que foi transportada do interior do sólido. Os mecanismos mais importantes desse transporte são:

difusão líquida, difusão de vapor e fluxo de líquido e de vapor. O conhecimento do conteúdo inicial e final (equilíbrio) de umidade do material, da relação da água com a estrutura sólida e do transporte da água do interior do material até a sua superfície possibilitam fundamentar o fenômeno da secagem. O fenômeno da secagem para materiais biológicos não pode ser generalizado, pois cada diferente material possui características próprias e propriedades que podem sofrer importantes alterações durante a secagem (SANTOS, 2011).

A Figura 2 descreve as curvas de secagem em relação a temperatura- umidade. A curva (a) é a curva de secagem e representa a diminuição do teor de água do produto durante a secagem, obtida relacionando-se o conteúdo de umidade do produto em base seca (X), com a o tempo de secagem (t). Esta curva pode ser obtida por pesagens sucessivas do produto durante a secagem em determinada condição de secagem estabelecida e constante. A curva (b) representa a velocidade (taxa) de secagem do produto, isto é, a variação do conteúdo de umidade do produto por unidade de tempo (dX/dt) em relação à evolução do tempo, sendo a curva obtida pela diferenciação da curva (a). Por fim, a curva (c) representa a evolução da temperatura no produto durante a secagem.

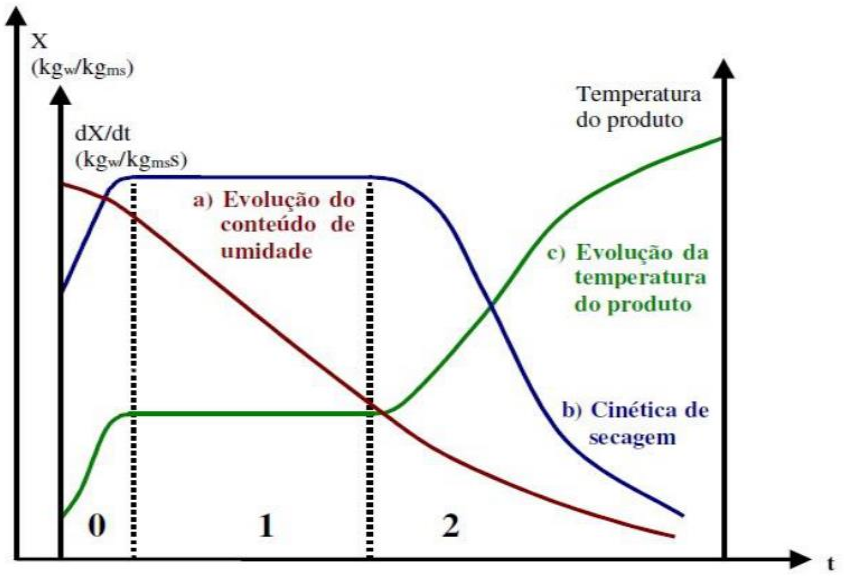

Figura 2. Curvas típicas de evolução da temperatura e da umidade do produto durante a secagem.

Fonte: (PARK; YADO; BROD, 2001).

Na secagem de frutas e hortaliças, o período de taxa decrescente é importante. Nessa fase as partes externas do material já estão secas, enquanto o interior ainda pode conter quantidades significativas de água. A partir desse ponto, o processo consome grandes

quantidades de energia e os atributos físicos, sensoriais e nutricionais do produto podem ser prejudicados devido à elevação da temperatura (NIJHUIS et al., 1996).

Uma possibilidade é o uso do ultrassom na secagem. Esta estratégia é próspera por atuar sem prejudicar as principais características e a qualidade dos produtos (MADHU et al., 2019). Assim, apresenta potencial para aplicação na secagem dos alimentos que são sensíveis ao calor, porque possibilita a remoção da umidade dos alimentos mais rapidamente e à temperatura mais baixa do que nos sistemas de secadores de ar quente tradicionais (RODRÍGUEZ et al., 2018). A vibração acústica produzida pelo ultrassom gera compressão e expansão sucessivas do material, o que ocasiona tensão na estrutura. Além disso, a cavitação produzida pelo ultrassom, que ocorre na fase líquida dentro da amostra úmida, gera implosões assimétricas de bolhas de cavitação próximas à superfície sólida da amostra, levando à liberação parcial de um pouco de água ligada à estrutura sólida (RODRÍGUEZ et al., 2018).

Um estudo feito por Martins et.al. 2022 onde observou o efeito da cinética de secagem em batata yacon em uma temperatura de 50°C, as amostras que foram submetidas a um pré-tratamento com ultrassom combinado com etanol obtiveram resultados mais satisfatórios, ou seja, o pré-tratamento com etanol combinado com ultrassom proporcionou a maior redução no tempo de secagem para atingir 25% de teor de umidade comparados aos que não se submeteram a esse procedimento.

3. Tecnologia de ultrassom como pré-tratamento no processo de secagem de vegetais

A tecnologia de ultrassom (US) é baseada em ondas mecânicas, em uma frequência acima do limiar de audição humana (> 20 kHz). No processamento de alimentos, de acordo com a intensidade das ondas ultrassônicas, o ultrassom é classificado em ultrassom de baixa intensidade (< 1 $W.cm^{-2}$) e ultrassom de alta intensidade (geralmente na faixa de 10 – 1000 $W.cm^{-2}$) (SORIA; VILLAMIEL, 2010).

A eficiência do ultrassom está relacionada principalmente ao fenômeno de cavitação, que consiste na formação, crescimento e colapso de bolhas que geram intenso calor e pressão, além de energia mecânica e química localizada (OJHA; TIWARI; O'DONNELL, 2018). As bolhas de cavitação resultam em micro correntes de fluxo que, associado ao gradiente de alta velocidade e de cisalhamento, alteram as características do meio e a porosidade dos alimentos.

A aplicação desta tecnologia associada com temperatura (termossonicação) permite maior eficiência na inativação microbiana e na manutenção da qualidade físico-química e sensorial de sucos processados por US (GUERROUJ et al., 2016). Além disso, pode promover

modificações nas estruturas dos constituintes dos alimentos, proporcionado uma redução do tamanho das partículas com efeito de homogeneização e estabilização de diferentes produtos alimentícios (AADIL et al., 2013; ERTUGAY; BAŞLAR, 2014; ROJAS et al., 2016; CAMPOLI et al., 2018; OJHA; TIWARI; O'DONNELL, 2018; CHEN et al., 2019).

O processamento ultrassônico consiste basicamente em imergir os alimentos em um líquido e submeter posteriormente de todo esse ao ultrassom. Frutas e vegetais muitas vezes passam por esse tratamento com o objetivo de modificar suas estruturas de tecido interno, o que pode facilitar a remoção da água (FIJALKOWSKA et al., 2016; RODRÍGUEZ et al., 2019). Na Figura 3 estão representados processos de US no pré-tratamento de vegetais utilizando o ultrassom de banho.

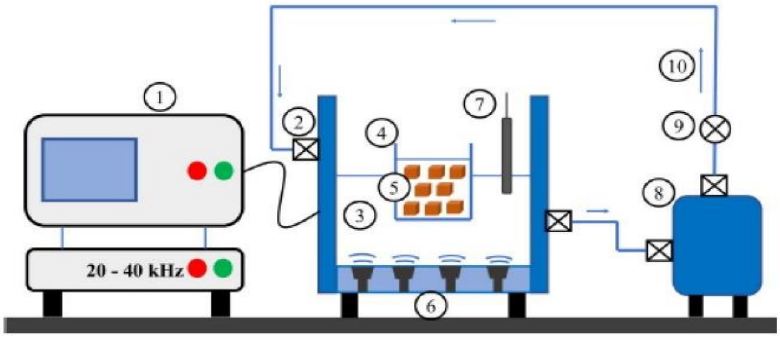

Figura 3. Dispositivos de pré-tratamento de banho ultrassônico.

Fonte: XU et al., 2021.

O Sistema de banho ultrassônico é composto por: 1. Gerador ultrassônico, 2. Válvula, 3. Meio líquido, 4. Proveta, 5. Amostras, 6. Transdutores ultrassônicos, 7. Termômetro, 8. Tanque de resfriamento, 9. Bomba, 10. Água recirculante. Na Tabela 2 encontra-se trabalhos referentes a otimização de secagem de produtos de origem vegetal utilizando a técnica de ultrassom como pré-tratamento.

Tabela 2 - Uso do pré-tratamento por ultrassom na secagem de produtos de origem vegetal

Matriz alimentícia	**Condições de Secagem: Potencia/Temperatura**	**Otimização de Secagem**	**Referência**
Cenoura	US (60 °C)	As amostras de cenoura atingiram a temperatura do ar de secagem mais rápido: após 20 min em 200W e após 25 min em 75W e 125W.	KROEHNKE et al., 2018

Pimenta vermelha	US (30, 50, 70 °C)	Os efeitos do US na taxa de secagem foram maiores em temperaturas mais baixas. Em temperaturas mais altas, o maior nível de energia fornecida pelo ar de secagem reduziu o efeito do US.	CÁRCEL, 2019
Kiwi	US (5, 10 e 15 °C)	O tempo de secagem diminuiu 62 %, 65 % e 55 % a 5, 10 e 15 °C, respectivamente.	VALLESPIR et al., 2019
Lichia	US (65°C)	O tempo total de secagem sem US (8,5 h) foi cerca de duas vezes menor com US (4,0 h).	CAO et al., 2020
Morango	US (200 W/25 min)	O menor tempo de secagem foi verificado nas amostras pré-tratadas com US	ZHANG, 2020
Quiabo	US (40kHz; 25W/L; 30min)	A taxa de secagem aumentou em quiabo pré-tratado com US em relação ao controle.	XU, 2021
Batata-doce	US (25°C; 30kHz; 30min; 200, 400 e 600W)	Maior potência ultrassônica, resultou em declínio mais rápido na taxa de umidade.	WU, 2020
Beterraba	US (40kHz; 180 W; 5 e 10min)	O tratamento com ultrassom resultou na menor atividade de água das amostras secas.	CIURZYNSKA, 2021
Batata Yacon	US (50°C)	O pré-tratamento com etanol combinado com ultrassom proporcionou a maior redução no tempo de secagem para atingir 25% de teor de umidade tanto para o vegetal branqueado quimicamente (redução de 30,1%) quanto para o vegetal branqueado termicamente (redução de 61,2%).	MATINS, et. al. 2022

Fonte: Da autora, 2023.

De acordo com trabalhos apresentados na área de secagem de vegetais utilizando o ultrassom como pré-tratamento, verificou-se que a tecnologia pode ser uma interessante estratégia para otimizar o tempo de secagem desses produtos. Consequentemente, o pré-

tratamento com US pode ser uma alternativa para a conservação de elementos funcionais presentes em frutas e em outros vegetais submetidos à secagem.

4. Adição de probióticos em matrizes vegetais

O termo probiótico, de origem grega, significa “para vida”. Foi inicialmente definido como compostos ou extratos de tecidos capazes de estimular o crescimento microbiano (CHEN; WALKER; 2005). Atualmente, os probióticos são definidos como microrganismos vivos que, quando administrados em quantidades adequadas, conferem benefícios à saúde do hospedeiro (HILL et al., 2014).

Para que os efeitos benéficos ocorram, de acordo com a Agência Nacional de Vigilância Sanitária (ANVISA), a dose mínima diária da cultura probiótica considerada terapêutica é de 10^8 a 10^9 UFC (Unidades Formadoras de Colônia), o que corresponde ao consumo de 100 g de um produto que contenha 10^6 a 10^7 UFC/g ou mL (ANVISA, 2013). Contudo, para atender às especificações de um alimento probiótico, a bactéria deve ser inócua, possuir viabilidade para suportar a estocagem e o transporte, tolerar o pH do suco gástrico e possuir propriedades de resistência a fagos e ao oxigênio (MELO et al., 2016). Os produtos contendo probióticos podem ser divididos em dois tipos: produtos probióticos lácteos, como iogurte, queijo, sorvete, fórmula infantil, bebidas com soro e sobremesas lácteas, e produtos probióticos não lácteos, como grãos, frutas, hortaliças, sucos, doces, alimentos para bebês, produtos à base de carne, dentre outros (MOHAMMAD et al., 2016).

Dentre as principais matrizes alimentares probióticas não lácteas destacam-se as frutas, hortaliças e seus subprodutos (MARTINS et al., 2020). Entre as frutas, as maçãs têm sido estudadas como um carreador adequado para células probióticas, devido às suas propriedades nutricionais e funcionais (EMSER et al., 2017).

Estudos recentes explana que frutas apresentam características próprias que podem parecer a aquelas encontradas no trato gastrointestinal humano, como acidez, superfícies irregulares que estimulam a adesão celular, e presença de fatores anti-nutricionais. Com isso, devido às condições intrínsecas das matrizes vegetais, as bactérias isoladas dessas fontes podem apresentar melhor adaptação às condições de processamento. (FILANNINO et al., 2018; GEORGE et al., 2018; KUMAR et al., 2015).

A produção dos alimentos probióticos vêm crescendo vertiginosamente ao longo dos últimos anos e dados recentes indicam que esses produtos representam cerca de 70 % do mercado de alimentos funcionais (MARKETS, 2020). Embora os produtos lácteos sejam as

principais matrizes carreadores de probióticos, esses produtos apresentam alguns desafios para certos grupos de consumidores. Cerca de 65 % da população mundial sofre de intolerância à lactose e outras doenças derivadas do consumo desses produtos, como alergia à proteína do leite. Esses problemas de saúde são tendência crescente de filosofias alimentares, como vegetarianismo e veganismo, que promovem uma mudança no consumo em direção a alimentos não lácteos, como cereais fermentados com probióticos como substitutos aos produtos lácteos, frutas enriquecidas com probióticos, além de sucos de frutas e hortaliças (MANTZOURANI et al., 2019).

A viabilidade dos probióticos em frutas, vegetais crus, sucos e bebidas fermentadas depende dos parâmetros intrínsecos dos alimentos, como o conteúdo de nutrientes, como carboidratos e proteínas, pH, potencial de oxirredução, atividade de água, bem como dos fatores extrínsecos como as condições de estocagem (GARCIA et al., 2016; FESSARD; REMIZE, 2019). Na Tabela 3 encontram-se estudos que avaliaram a viabilidade de probiótico em frutas.

Tabela 3. Estudos sobre a viabilidade de probiótico em frutas.

Matriz alimentar	**Microrganismo utilizado**	**Viabilidade**	**Referência**
Maçãs simbióticas minimamente processadas	*L. Rhamnosus GG*	10^{7} –10^{8} UFC/g^{-1}	RÖßLE, BRUNTON,et al. (2010)
Coquetel de frutas de cenoura, aipo e maçã	*L. acidophilus LA-5*	Acima de 10^{7} UFC·mL^{-1}	NICOLESCO E BURULEANU (2010)
suco de maçã, tangerina e abacaxi	*Lactobacillus salivarius spp. salivarius CETC4063 e Lactobacillus acidophilus CECT903*	Acima de 10^{7} UFC·g^{-1}	BETORET, et al. (2012)
Banana	*L. rhamnous*	7-8 log UFC/g	HUERTA-VERA et al., 2017
Damasco	*B. lactis* Bb-12;	Todos os probióticos mantiveram viabilidade	BUJNA et al., 2018

	B. longum Bb-46; *L. casei* 01; *L. acidophilus* La-5	> 8 log UFC/g.	
Bebida à base de soja vegetal	*L. acidophilus La 5, B. animalis Bb 12 e S. thermophilus*	$>10^{6}$ UFC mL^{-1}	BATTISTINI, et al., 2018
Jaca desidratada	*L. casei*	> 7 log UFC/g.	BERNARDINO et al., 2020
Bebida mista de abacaxi e juçara	*Lactobacillus rhamnosus GG*	$> 10^{6}$ UFC/mL	ANDRADE, et al., 2020
Sobremesas de inhame e manga Ubá	*L. plantarum*	*>8 log UFC/g* $^{-1}$	COSTA et al., 2020

Fonte: Da Autora, 2023.

Algumas estirpes de probióticos podem apresentar importantes efeitos à saúde associados às suas propriedades probióticas, como modulação da microbiota (COSTA et al., 2018), propriedades hipocolesterolêmicas, anti-hipertensivas e hipoglicêmicas (VERÓN et al., 2019) e efeitos imunomoduladores (FAKRUDDIN et al., 2017).

Lactobacillus e *bifidobacterium* são os gêneros mais comumente usados comercialmente como probióticos em alimentos. Entre estes, *Lacticaseibacillus rhamnosus* GG (LGG) é um dos principais probióticos estudados. Esse microrganismo se apresenta na forma de bastonete, não formador de esporos, anaeróbio facultativo e gram-positivo (GORBACH et al., 2017). Dentre os principais benefícios relatados de *Lacticaseibacillus rhamnosus* GG destaca-se a melhoria da saúde intestinal, prevenindo infecções gastrointestinais e reduzindo certos sintomas alérgicos (SPACOVA et al., 2018).

Frutas e hortaliças estão entre os alimentos não-lácteos potencialmente carreadores de probióticos e são mais uma opção de alimentos funcionais para os consumidores. Portanto, com o intuito de oferecer novas alternativas de produtos não-lácteos funcionais de elevada vida de prateleira, esse projeto visa estudar o efeito da tecnologia de ultrassom para acelerar a secagem de goiaba adicionada de *Lacticaseibacillus rhamnosus* GG ATCC 53103 visando introduzir no mercado um produto saudáveis, estável e funcional.

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CAPÍTULO 2

Manuscript: Effect of ultrasound on drying kinetics of potentially probiotic guava (Psidium guajava), viability of *Lacticaseibacillus rhamnosus* GG and functional quality.

Trabalho submetido à revista Food Research International. Daniele J. R. Gonçalves, Nataly de A. Costa, Maria José do A. e Paiva, Vanessa C. de Oliveira, Nicole M. A. Maia, Isabela S. Magalhães, Larissa L. R. Borges, Paulo C. Stringheta, Érica N. R. Vieira, Eliane M. F. Martins, Bruno R. de C. Leite Júnior. Ultrasonic pre-treatment to enhance drying of potentially probiotic guava (*Psidium guajava*): Impact on drying kinetics, *Lacticaseibacillus rhamnosus* GG viability, and functional quality.

CAPÍTULO 2

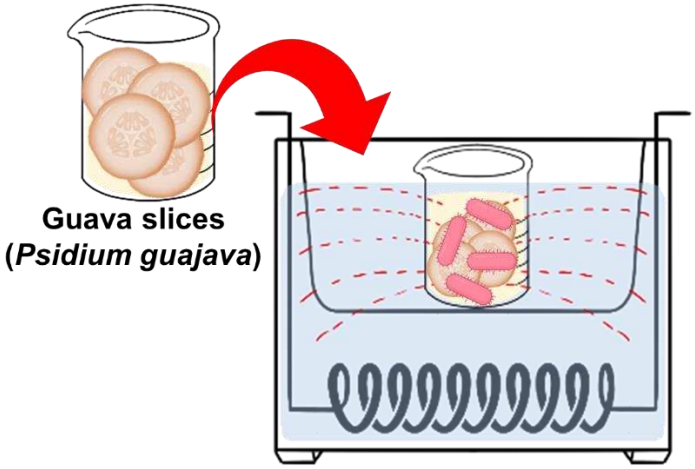
Effect of ultrasound on drying kinetics of potentially probiotic guava (Psidium guajava), viability of *Lacticaseibacillus rhamnosus* GG and functional quality.

Abstract

In this study, the effects of ultrasound (US) on the acceleration of drying of potentially probiotic guava were evaluated, including its impact on drying kinetics, *Lacticaseibacillus rhamnosus* GG viability, and functional quality of the product during drying. Guava slices were pre-treated by US (38 W/L, 25 kHz) for 15 and 30 min and immersed for 15 or 30 min in a solution containing *L. rhamnosus* GG assisted or not by US. After pre-treatments, the samples were subjected to convective drying at 60°C to evaluate product quality. Based on the results, US pre-treatment improved the drying rate (up to 59%) and reduced the drying time (up to 31%) to reach 25% moisture compared to non-sonicated samples. The reduction in drying time (from ~6 hours to ~4 hours for samples processed by US) was crucial for maintaining the probiotic viability in the dehydrated guavas. These samples showed counts of 6.15 to 7.00 $CFU.g^{-1}$ after 4 hours (highlight for the sample immersed in probiotic solution assisted by US for 30 min), while the control samples required 6 hours of drying and reached counts of 4.17 to 4.45 $CFU.g^{-1}$. US pre-treatment did not affect the color parameters of the samples before drying ($p>0.05$), and both samples had similar behavior during drying. The functional compounds were reduced during drying ($p<0.05$), however, US pre-treated samples had lower reductions in vitamin C content (up to 20%), phenolic compounds (up to 41%) and antioxidant capacity (up to 47%) compared to control samples (up to 52%, 81% and 61%, respectively). Thus, US pre-treatment reduced the drying time for guava slices and minimized the thermal impact on probiotic viability and functional compounds. Therefore, US pre-treatment is a strategy to produce potentially probiotic dehydrated guava.

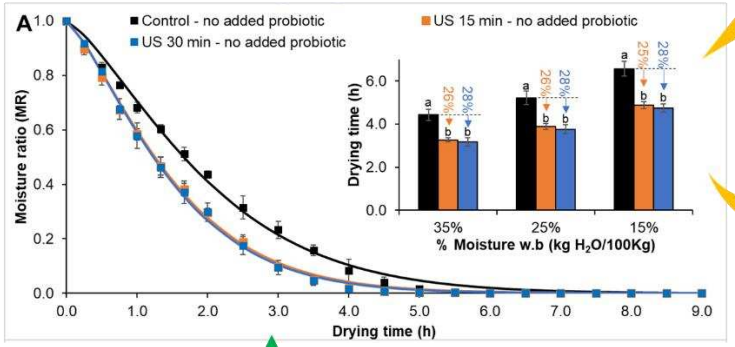
Keywords: Drying kinetics; Emerging Technologies; Functional compounds; Fruits and vegetables; Probiotic food; Ultrasound technology.

Graphical abstract



Different strategies:
US pre-treatment - *L. rhamnosus* GG addition

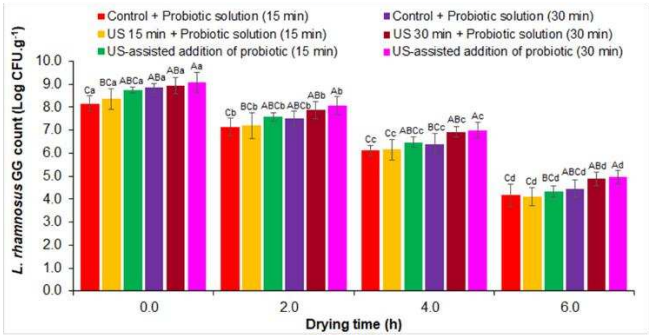
Drying process



US pre-treatment: ↑ drying rate (up to 59%)

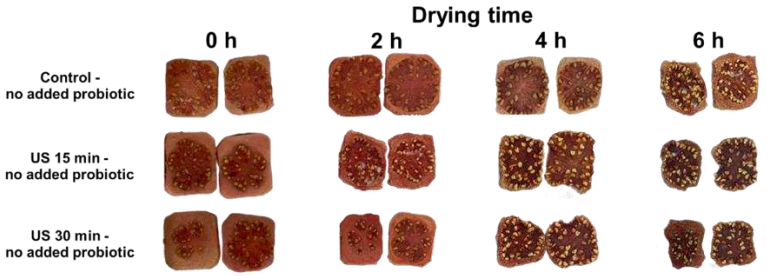
↓ drying time (up to 31%)

***Lacticaseibacillus rhamnosus* GG ATCC 53103 viability**



↑ probiotic viability of US pre-treated samples

Especially: US-assisted addition of probiotic (30 min)



Color parameters: similar behavior

Functional compounds reduction after drying (%)

US pre-treated samples x control samples:

- **Vitamin C content: <20% x <52%**
- **Phenolic compounds: <41% x <81%**
- **Antioxidant capacity: <47% x <61%**

↑ **functional quality**

1. Introduction

Guava (*Psidium guajava* L.) is native to America, especially in tropical and subtropical countries such as Cuba, Brazil, and Mexico (Forato et al., 2015). This fruit has an interesting nutritional quality, with emphasis on the high content of vitamin C, phenolic compounds, and minerals (especially calcium and selenium) (Santos et. al., 2020). The guava can be consumed fresh, however, due to its high respiratory rate, it ripens quickly during storage, reducing its shelf life (Vishwasrao & Ananthanarayan, 2016). Thus, processing guava to produce derivatives such as pulp, jelly, jam, pickles, juice, and sweets, as well as the drying of guava slices to produce dehydrated guava are strategies for extending the shelf life of this fruit (Kek et al., 2013).

One of the main methods used for fruit dehydration is convective drying, due to the low cost of equipment and simple operating conditions (Defraeye & Radu, 2017). However, this drying method presents some limitations such as long processing time, low productivity, high energy consumption, high temperatures, among other factors that directly impact the nutritional and sensory quality of the product (Park et al., 2001). Therefore, the application of emerging technologies in the processing of this fruit before drying can be an interesting strategy to accelerate the drying rate and overcome these limitations (Martins et al., 2022). In this context, ultrasound (US) has been used as a pre-treatment before guava drying to increase the drying rate and reduce processing time (Kek et al., 2013; Santos et al., 2020). The application of ultrasound can provide an increase in the effective diffusivity of water and in the mass transfer coefficient (Defraeye & Radu, 2017). In addition, the reduction in drying time of US pre-treated fruits can minimize the nutritional losses of these foods, resulting in products with better quality, cost, and yield (Dolas et al., 2019).

In parallel, the concern for healthy eating is gaining attention from the population, and consumers' nutritional demands are changing, aiming for the search for nutritious, healthy, and functional foods (Aguiar et al., 2019). Among the various products, probiotic foods stand out (Zhou et al., 2020). Usually, these probiotics are used in dairy products. However, studies show that these microorganisms have great potential for application in products of plant origin (Montanari et al., 2020; Pires et al., 2020; Prates et al, 2020; Oliveira et al., 2020).

According to the Food and Agriculture Organization of the United Nations and the World Health Organization, probiotics are live microorganisms that, when ingested in appropriate quantities, bring health benefits to the host (WHO/FAO, 2002). Among the main studied microorganisms, *Lacticaseibacillus rhamnosus* GG is a probiotic strain that has been attracting the attention of the industrial and scientific community due to its ability to adhere to

the intestinal mucosa and its resistance to bile acid (Francavilla et al., 2010; Kara et al., 2019; Zheng et al. 2020).

In this context, although recent studies show the positive impact of US pre-processing in reducing the drying time of fruits and vegetables and the good adaptation of probiotics in plant matrices, there are no studies in the literature that have evaluated the effect of US pre-processing of guava added with *L. rhamnosus* GG aiming to optimize the drying time and maintain the viability of the probiotic in the dehydrated product. Moreover, there are no studies in the literature showing the impact of these pre-processing techniques on the functional quality (phenolic compounds and antioxidant activity) of guava during drying. Therefore, aiming to expand the use of US technology and offer nutritious and functional products to consumers, this study aimed to evaluate the impact of ultrasound on accelerating the drying of potentially probiotic guava, evaluating its effect on drying kinetics, *Lacticaseibacillus rhamnosus* GG viability, and functional quality of the product during drying.

2. Material and Methods

2.1 Sample preparation

Fresh guavas (*Psidium guajava* L.) were obtained from the local market (Viçosa, MG). Initially, to sanitize the peels, guavas were soaked in a solution with 100 mg/L of active chlorine for 10 minutes. Afterward, the fruits were washed in a solution containing 10 mg/L of active chlorine. Subsequently, the guavas were peeled in a food processor (model CL50 Ultra, Robot Coupe, Narcel©, Paraná, Brazil) to produce cylindrical slices of guava with a standardized size of 4.0 cm diameter × 0.5 cm thickness. After cutting, the guava slices were subjected to chemical blanching. For this, the guava slices were immersed in a beaker containing 2% citric acid solution (w/v) for 5 minutes at 25°C. Afterward, the samples were drained for further preprocessing.

2.2 Ultrasound pretreatment and incorporation of the probiotic in guava slices

Experimentally, 9 treatments were performed by combining pre-treatment with ultrasound (US) for 15 and 30 min, as well as adding the probiotic culture of *Lacticaseibacillus rhamnosus* GG ATCC 53103 (Culturelle®) for 15 and 30 min assisted or not by US. These treatments are illustrated in Figure 1 and are denominated as follows: T1 - sample without ultrasonic pretreatment and without addition of *L. rhamnosus* GG; T2 - sample pretreated by US for 15 min without addition of *L. rhamnosus* GG; T3 - sample pretreated by US for 30 min

without addition of *L. rhamnosus* GG; T4 - sample without ultrasonic pretreatment immersed in *L. rhamnosus* GG solution for 15 min; T5 - sample pretreated by US for 15 min and immersed *in L. rhamnosus* GG solution for 15 min; T6 - sample immersed in *L. rhamnosus* GG solution for 15 min assisted by US; T7 - sample without ultrasonic pretreatment immersed in *L. rhamnosus* GG solution for 30 min; T8 - sample pretreated by US for 30 min and immersed in *L. rhamnosus* GG solution for 30 min; T9 - sample immersed in *L. rhamnosus* GG solution for 30 min assisted by US. In the next subsections 2.2.1 and 2.2.2 these steps are presented in detail.

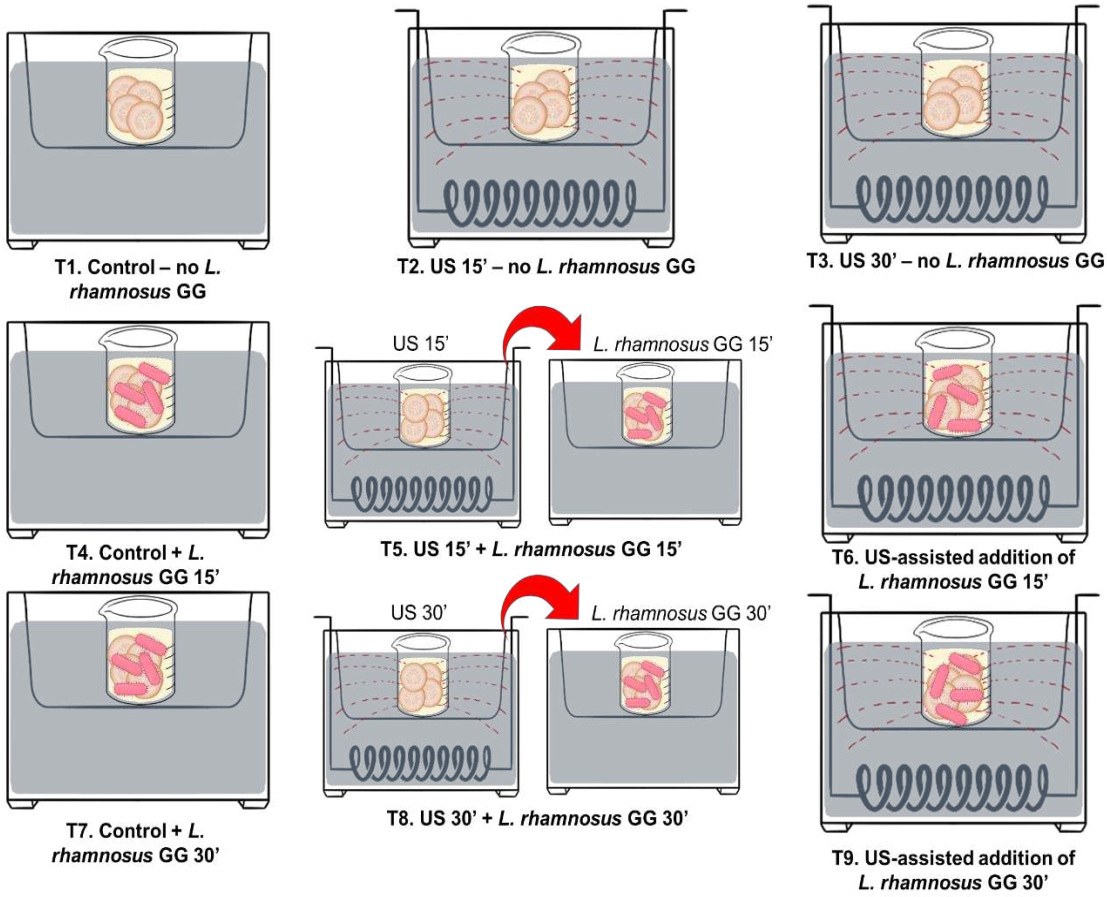


Figure 1. Illustration of ultrasonic pre-treatments and addition of *L. rhamnosus* GG to guava slices.

2.2.1. Ultrasonic pretreatment

In this study, 25 guava slices were placed in a beaker containing 300 mL of sterilized distilled water and treated with ultrasound for either 15 or 30 minutes. The ultrasonic treatment was performed using an ultrasonic bath (Unique, model USC 2800 A, Indaiatuba, Brazil) with internal dimensions of 30 x 24 x 15 cm, a nominal capacity of 9.5 L, a nominal power of 450 W, and a frequency of 25 kHz. The power transmitted to the solution was measured using the calorimetric method described by O'Donnell et al. (2010), and the resulting volumetric power

was 38 W/L. Before starting the ultrasonic treatment, the ultrasonic bath was filled with 6.5 L of distilled water. The sample beaker was positioned at the location of maximum ultrasonic intensity, which was determined beforehand using the aluminum foil method (Vinatoru, 2015). To maintain a constant temperature of 25 ± 2°C, a stainless-steel heat exchanger was used in the ultrasonic bath, and water recirculation was ensured by an external ultra-thermostatic bath (SSDu 10L, Solidsteel, Piracicaba, Brazil). The processes were conducted in triplicate. Once the ultrasonic treatment was completed, the samples were taken out from the water and drained for 3 min with further convective.

2.2.2 Incorporation of the probiotic in guava slices: Preparation and addition

The freeze-dried probiotic culture of *Lacticaseibacillus rhamnosus* GG ATCC 53103 (Culturelle®) containing 10 log CFU.g^{-1} was activated using the method described by Costa et al. (2023). The culture was cultivated twice in Man Rogosa and Sharp broth (MRS) at 37 °C for 48 hours. After incubation, the broth was centrifuged at 5000 rpm for 10 minutes at 8°C, and the supernatant was discarded. The resulting pellet was resuspended twice in sterile saline solution (0.85%) and centrifuged at 5000 rpm for 10 minutes at 8°C. The pellet obtained showed counts of approximately 12 log CFU.g^{-1}, consistent with the results reported by Costa et al. (2023). The pellet was then stored in sterile centrifuge tubes and refrigerated at 4°C until use.

Subsequently, the pellet was resuspended in sterile distilled water at a ratio of 1:100, i.e., for every gram of pellet, 100 mL of water was added to obtain at least a concentration of 10 log CFU.mL^{-1}. Thus, for the production of guava slices with probiotics, 25 guava slices were immersed in 300 mL of probiotic aqueous solution (concentration of 10 log CFU.mL^{-1}) and this suspension was kept in contact with the guava slices for 15 and 30 min at 25 °C. In addition, this process was also carried out under ultrasound (US-assisted process) in the same ultrasonic conditions as described in section 2.2.2. In parallel, samples pre-treated with US for 15 and 30 min were also immersed in probiotic solution for the same time (15 and 30 min, respectively) (Figure 1). After the processes, the guava slices were removed from the solution and drained for 3 min with further convective

To conduct a comparative evaluation, an unprocessed sample (control) was also included in addition to the samples that underwent US pre-treatment and probiotic addition. The control sample was cut to a standard size and subjected to the same bleaching process as the other treatments. Furthermore, it was dried under identical conditions as the other samples to ensure a fair comparison.

2.3 Drying process

In order to investigate the drying kinetics, a fixed-bed dryer (tray dryer) made of stainless steel (model SSD, 85L, Solidsteel, Piracicaba, São Paulo) was used to convectively dry the samples at a temperature of 60 °C until a constant weight was attained. The dryer's operating system involved circulation and renewal of drying air at an airspeed of 1m/s, with hot air flowing vertically through its trays. To monitor the drying process, the samples were weighed using a semi-analytical balance (Mark M2202, BEL Equipamentos, Piracicaba, Brazil) at intervals of 15 minutes during the first hour of drying, every 20 minutes during the second hour, and every 30 minutes thereafter until equilibrium was reached.

The moisture content at each stage was determined through a mass balance calculation, which involved measuring the initial moisture content of the samples after processing and the final moisture content after complete drying at 105°C using an oven (Q819V2, QUIMIS, Diadema, Brazil) until a constant weight was achieved.

Drying curves were plotted as a function of the dimensionless moisture content (MR) versus time during the drying process and calculated according to equation 1 (Eq. (1)) (Ricce et al., 2016).

$$MR(t) = \frac{M_t - M_e}{M_p - M_e} \quad (Eq.1)$$

Where Mt is the moisture content (d.b.) (that is, kg of water/100 kg of dry matter) at time (t) of the drying process, M_e is the equilibrium moisture content (determined based on the final moisture of samples that have exhibited a mass variation of less than 0.02 g over the last six recorded measurements) and M_p is the initial moisture (d.b.) after pre-treatments. In the case of control samples, the initial moisture (M_p) is equivalent to the moisture content before pre-treatments (involving the *L. rhamnosus GG* addition or US treatment). Thus, the samples start the drying process with MR values equal to one.

2.3.1 Drying kinetics

The drying kinetics was assessed using the Page Model (Eq.2), where MR (t) is the dimensionless moisture content at a given drying time (t), k (h^{-n}) corresponds to the drying rate constant, and n is the dimensionless drying constant. The parameter k can be understood as a "diffusion coefficient" that is associated with the geometry of the sample. The drying constant parameter (n) provides information about the “type of diffusion” that occurs during the drying

process. A value of n>1 suggests superdiffusion, whereas a value of n<1 suggests subdiffusion (Simpson et al., 2017).

$$MR(t) = \exp(-k \cdot t^n) \quad (Eq. 2)$$

The evaluation of model fitness was carried out using the determination coefficient (R^2), the root means square deviation value (RMSD) calculated using equation 3 (Eq.3), and by plotting the values obtained by the model (M_{model}) as a function of the experimental values ($M_{experimental}$). The regression of these data to a linear function (Eq. 4) results in three parameters: the linear slope (a; which ideally should be close to one), the intercept (b; which ideally should be close to zero), and the coefficient of determination (R^2; which ideally should be close to one).

$$RMSD = \sqrt{\frac{\sum_{i=1}^{n}(M_{experimental} - M_{model})^2}{n}} \quad (Eq. 3)$$

$$M_{model} = a \cdot M_{experimental} + b \quad (Eq. 4)$$

2.4. *Lacticaseibacillus rhamnosus* GG ATCC 53103 viability in guava slices during drying

L. rhamnosus GG ATCC 53103 viability was determined immediately after sample processing (time 0 h - before drying) and after 2, 4, and 6 hours of drying. The analysis was performed using the pour plate technique with MRS agar (Merck, Darmstadt, Germany) supplemented with bromocresol purple and calcium carbonate (Richter & Vedamuthu, 2001). During the analysis, the samples were incubated in anaerobic jars at a temperature of 37 °C for up to 72h.

2.5. Surface color of guava slices during drying

The color of guava slices on their surface was assessed before (time 0h) and after 2, 4, and 6 hours of drying using COLOR QUEST II tristimulus colorimeter equipped with a Universe software from Hunterlab, Reston, VA. The CIELab scale was used for color determination using the coordinates L*, a*, b*, where L* represents the level of luminosity on a scale from 0 to 100, with 0 being black and 100 being white. The a* axis represents the

variation between green (negative values) and red (positive values), while the b* axis represents the variation between blue (negative values) and yellow (positive values).

In addition, the total color difference (ΔE) between the fresh sample (not pretreated - defined as reference) and the samples subjected to different pretreatments (US treatment and/or *L. rhamnosus* GG addition) was calculated according to equation 5 (Eq. 5). Six readings were taken at different locations on the product for each sample.

$$\Delta E = \sqrt{(\Delta \mathrm{L}*)^2 + (\Delta \mathrm{a}*)^2 + (\Delta \mathrm{b}*)^2} \quad (Eq. 5)$$

2.6. Functional quality of guavas during drying

2.6.1. Vitamin C content

The vitamin C content was determined in the guava samples before (time 0h) and after 2, 4, and 6 hours of drying using Tillman's method according to Drevinskas et al. (2017). This analysis was performed through titration using Tillman's reagent and monitored through the color change due to the reduction of 2,6-dichloroindophenol. The vitamin C content was expressed as mg per 100 g of dry matter (mg/100g DM).

2.6.2. Extraction of samples for total phenolic content and antioxidant capacity

The extraction for total phenolic analysis and antioxidant activity was carried out according to the methodology described by Gualberto et al. (2021), with modifications. 8 g of sample were ground in a mixer with 160 mL of 80% (v/v) ethanol. Extraction was performed in an ultrasonic bath (Elmasonic TI-H10, Elma, Germany) at 45 kHz for 30 min at 40 °C. After sonication, the extracts were filtered through Whatman filter paper No. 1 and concentrated in a rotary evaporator (IKA RV 10 digital, Staufen, Germany) at 40 °C. After concentration, the volume of the extracts was measured in a volumetric flask and completed with distilled water to 25 mL. The extracts were stored frozen until the time of analysis.

2.6.3 Total phenolic compound (TPC) content

The quantification of total phenolic compounds determined before (time 0h) and after 2, 4, and 6 hours of drying. TPC was carried out according to the method described by Singleton & Rossi (1965). In test tubes, 0.6 mL of sample were mixed with 3 mL of Folin-Ciocalteau reagent (diluted 1:10 with water v/v) and 2.4 mL of 7.5% (w/v) Na_2CO_3 solution. After 1 h in the dark at room temperature, the absorbance was measured at 765 nm (UV-M51, Bel

Photonics, Monza, Italy). The TPC content was expressed as mg gallic acid equivalents (GAE) per g of dry matter (DM) - (mg GAE/g DM).

2.6.4. Antioxidant capacity: radical 2,2'-azinobis-3-etil-benzotiazolina-6-sulfonado (ABTS)

The samples were evaluated for their antioxidant capacity before (time 0h) and after 2, 4, and 6 hours of drying using [2,2′-azinobis(3-ethylbenzthiazoline sulfonic acid-6)] (ABTS) radical according to the method described by Re et al. (1999): 0.5 mL of sample (4 different dilutions) were added to 3.5 mL of ABTS radical solution (diluted in 80% ethanol to an absorbance of 0.700 ± 0.05 at 734 nm). After 6 minutes of reaction in the dark (room temperature), the absorbance was measured at 734 nm (UV-M51, Bel Photonics, Monza, Italy). The results were expressed as µmol Trolox equivalents (TE) per g of dry matter (DM) - (µmol TE/g DM).

2.7. Statistical analyses

The processes and analyses were conducted in three repetitions. Descriptive statistics (mean and standard deviation) were applied to the results. For comparing the means between treatments concerning the parameters obtained from the Page model, drying time for different moisture contents, color parameters (L*, a*, and b*), *L. rhamnosus* GG viability, as well as functional compounds, analysis of variance (ANOVA) was employed, followed by the Tukey test, with a significance level set at 5% probability ($p < 0.05$).

3. Results and Discussion

3.1 Drying of guava slices at 60 °C after pre-treatment by US and probiotic addition

The results of the drying kinetics of guava slices at 60°C after pre-treatment with US and addition of the solution containing *L. rhamnosus* GG are shown in Figure 2. Drying was carried out until the samples reached an equilibrium condition (constant weight), in which there were no significant differences in equilibrium moisture, with values ranging from 11.3 to 8.0% ($p>0.05$).

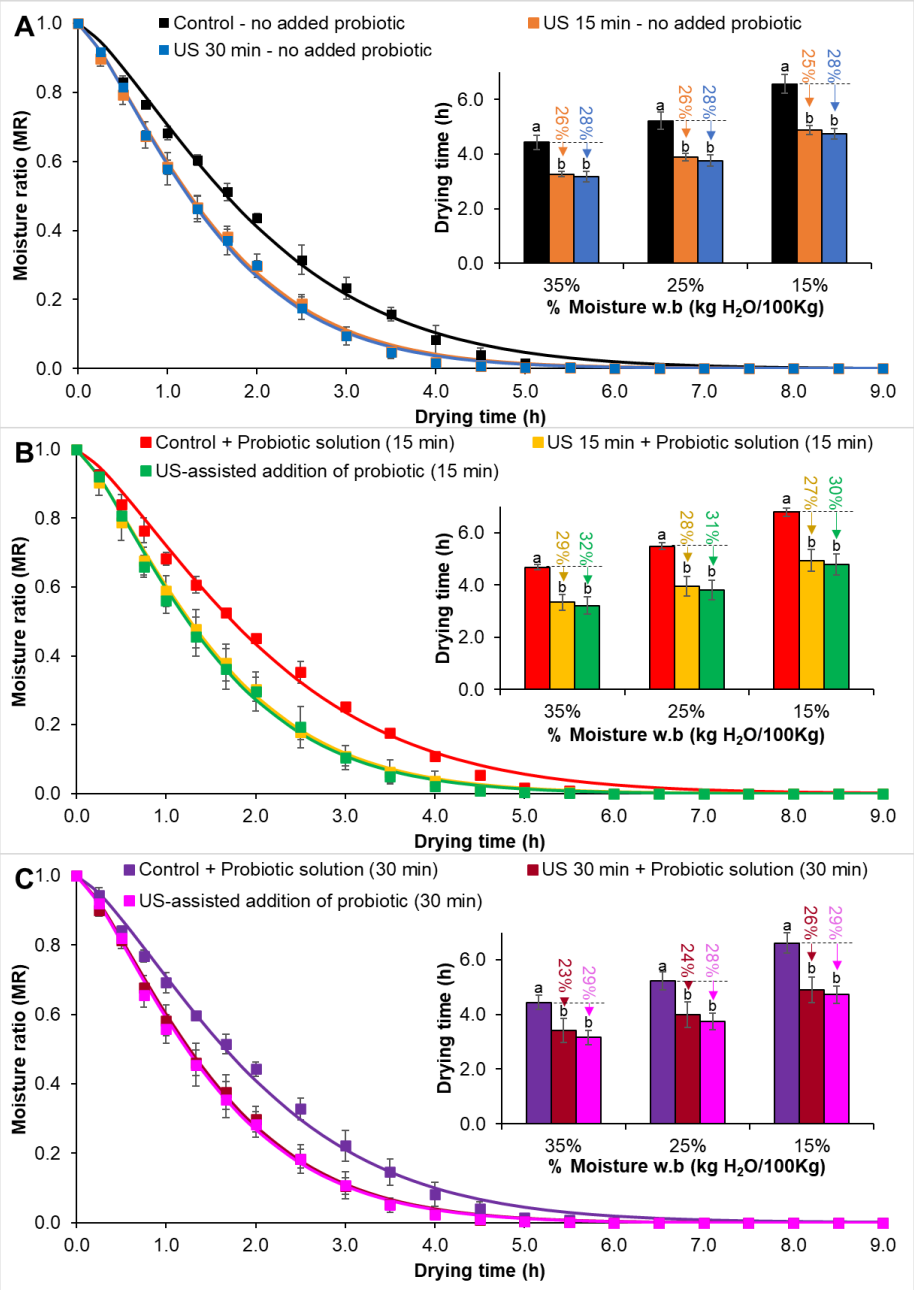


Figure 2. Dimensionless moisture (MR) behavior during time (t) of convective drying of guava slices at 60 °C after pre-treatment by US and probiotic addition (A: non-added; B: immersed in probiotic solution for 15 min; C: immersed in probiotic solution for 30 min).

Different lowercase letters in the same % Moisture indicates statistically significant differences between the different treatments by the Tukey's test at 5% ($p > 0.05$).

The data were fitted to the Page model (Eq. 2), and based on the obtained values for parameters a, b, RMSD, and R^2 (Eq. 3 and Eq. 4), the evaluated model was able to accurately describe the experimental data, with $R^2 > 0.998$, "a" value very close to 1 ($|a-1| < 0.0346$), "b" value close to 0 ($|b| < 0.0274$), and RMSD < 0.055. Figure 2 shows the "drying time", which represents the time required to achieve different moisture levels (35 to 15% w.b.) for samples

without probiotic (A), as well as for samples immersed in a probiotic solution for 15 min (B) or 30 min (C), treated or not treated by US.

From the results obtained, it was observed that US treatments reduced the drying time to reach all evaluated moisture levels (35 to 15%) regardless of the processing time (15 or 30 min) and the presence of probiotic ($p<0.05$) (Figure 2). Specifically, to reach a moisture content of 25% w.b. (considered the maximum desired final moisture (Jay et al., 2005)), it was found that samples pre-treated by US, with or without the addition of probiotic, showed reductions of 24 to 31% compared to their respective non-sonicated samples, regardless of the US pre-treatment time (15 or 30 min) ($p<0.05$) (Figure 2). Therefore, the US processes significantly contributed to facilitating water removal and, consequently, reducing the drying time, which demonstrates that US could be an interesting technology to minimize impacts on product quality. These results were similar to those found by Santos et al. (2021), who observed a 33% reduction in the drying time of carrot slices. Similarly, Kek et al. (2013) also observed a maximum reduction of 33% in the drying time of guava slices pre-treated with US, as well as Santos et al. (2020) who observed a positive impact of US in reducing the drying time of sliced guavas. In another study, Rojas & Augusto (2018) obtained a 23% reduction in the drying time of potato slices. These results were in line with expectations, considering that several studies have reported a reduction of less than 25% in drying time for different matrices treated with US.

Table 1 shows the parameters *k* and *n* of the Page model (Eq. 2) for the convective drying of guava slices at 60°C after pre-treatment by US and probiotic addition. The results for the parameter *k* indicate that the samples treated by ultrasound had better drying rates than those without ultrasound, regardless of the presence of probiotic and sonication time, with increases ranging from 45 to 59% ($p<0.05$). These values confirm the shorter time needed for drying the US samples when compared to those not processed. The explanation for this phenomenon may be related to the shear stress induced by ultrasound that breaks part of the cell walls, allowing more free water inside the fruit, resulting in a higher dehydration rate after heat transfer (Miano et al., 2016; Santos et al., 2020; Martins et al., 2022).

Table 1. Parameters k and n of Page Model (Eq. (2)) of convective drying of guava slices at 60 °C after pre-treatment by US and probiotic addition.

Sample	**Page model parameters**		
(Pre-treatment + Probiotic addition)	**k (h^{-1})**	**n**	**R^2**

Control - no added probiotic	0.35 ± 0.02^{b}	1.35 ± 0.07^{a}	0.998
US 15 min - no added probiotic	0.51 ± 0.04^{a}	1.32 ± 0.12^{a}	0.998
US 30 min - no added probiotic	0.53 ± 0.06^{a}	1.33 ± 0.09^{a}	0.999
Control + Probiotic solution (15 min)	0.33 ± 0.02^{b}	1.35 ± 0.07^{a}	0.998
US 15 min + Probiotic solution (15 min)	0.50 ± 0.06^{a}	1.32 ± 0.14^{a}	0.998
US-assisted addition of probiotic (15 min)	0.52 ± 0.05^{a}	1.33 ± 0.03^{a}	0.998
Control + Probiotic solution (30 min)	0.34 ± 0.03^{b}	1.38 ± 0.09^{a}	0.998
US 30 min + Probiotic solution (30 min)	0.51 ± 0.03^{a}	1.33 ± 0.03^{a}	0.999
US-assisted addition of probiotic (30 min)	0.53 ± 0.06^{a}	1.33 ± 0.03^{a}	0.999

Different lowercase letters in the same column indicate statistically significant differences among different treatments by the Tukey's test at 5% ($p<0.05$).

Regarding the drying constant parameter (n), which provides information about the "type of diffusion" occurring during the drying process, a value of $n>1$ suggests superdiffusion, while a value of $n<1$ suggests subdiffusion (Simpson et al., 2017). In this study, all samples had a value of $n>1$, indicating superdiffusion, with no difference between treatments ($p>0.05$). The formation of microchannels, through cavitation and mass transfer, due to the surface tension gradient formed (Marangoni effect), it was expected that samples treated with US would cause an increase in the *n* value. However, this was not observed. Therefore, changes in the *n* value may also be correlated with the structure of the cell wall, as well as with changes in the composition of the sample surface produced by the ultrasound process (Rojas et al., 2020a). In this context, according to Miano et al. (2016), when ultrasound is applied to the food matrix, it tends to form several channels with different shapes and directions. These cavities are formed randomly and may or may not connect to each other or to the external surface, which directly impacts mass transfer. A significant increase in diffusion and/or drying rate will only be observed if many channels are formed and as long as they are connected to the external surface of the sample (Miano et al., 2016; Rojas et al., 2020b; Martins et al., 2022). Otherwise, if few or isolated channels are formed, the liquid can be confined within the matrix, hindering mass transfer, and resulting in a subdiffusive system (Rojas et al., 2020b).

3.2. *Lacticaseibacillus rhamnosus* GG (ATCC 53103) viability in guava slices during drying

Probiotics are live microorganisms that, when consumed in sufficient quantities, bring health benefits to the individual (Hill et al., 2014). To exert the beneficial effect, the World Health Organization suggests the need for regular consumption of a product that presents a minimum concentration of 6 log CFU.g^{-1} of the probiotic (WHO/FAO, 2002). In this study, guava slices that were not sonicated or pre-treated by US for 15 and 30 min were immersed in a solution containing *Lacticaseibacillus rhamnosus* GG (ATCC 53103 - at a concentration of 10 log CFU.mL^{-1}) for 15 and 30 min. Additionally, samples were also added with *L. rhamnosus* GG in US assisted processes for the same processing time. Figure 3 shows the results of *L. rhamnosus* GG counts in guava slices subjected to different treatments before (time 0h) and after 2, 4, and 6 hours of convective drying at 60°C.

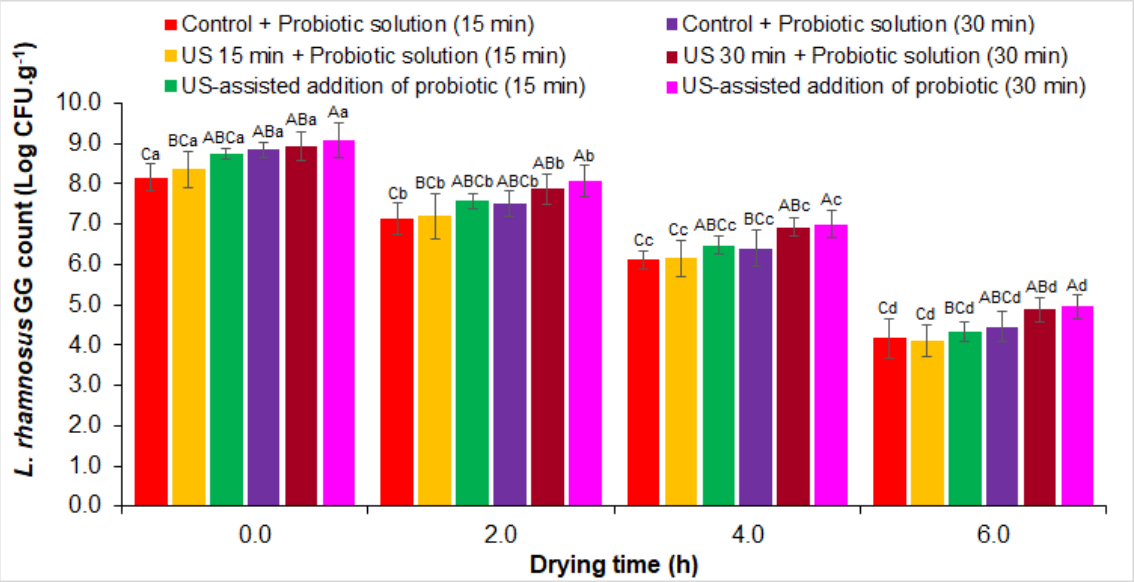


Figure 3. *Lacticaseibacillus rhamnosus* GG (ATCC 53103) count in guava slices during drying at 60 °C after pre-treatment by US and probiotic addition. Different uppercase letters indicate significant differences between the different treatments in the same drying time by the Tukey's test at 5% (p> 0.05) and different lowercase letters indicate significant differences between the different drying times in the same treatment by the same test. *Treatments without the addition of the probiotic showed counts <1 log CFU.g^{-1} at all times evaluated.

Samples without the addition of the probiotic presented counts <1 log CFU.g^{-1} at all evaluated times, confirming that the observed counts in samples added with *L. rhamnosus* GG are exclusively due to the presence of this microorganism. Initially, before starting the drying process, all treatments showed counts > 8.16 log CFU.g^{-1}, with a maximum count of 9.08 log CFU.g^{-1} for the sample immersed in probiotic solution for 30 min assisted by US. It is noteworthy that for the non-sonicated samples, the increase in immersion time (from 15 to 30 min) had a significant influence on the probiotic count ($p<0.05$). On the other hand, when ultrasound was used (either in pre-treatment or in assisted addition), no significant difference

was found in the count of *L. rhamnosus* GG with the increase from 15 to 30 min of contact with the probiotic ($p>0.05$). This result is interesting and shows that the use of US contributed to a better impregnation of the microorganism in the guava slices.

During drying, a reduction in the probiotic count was observed for all treatments evaluated ($p<0.05$), with counts ranging from 7.13 to 8.08; 6.11 to 7.00; and 4.10 to 4.96 $CFU.g^{-1}$ after 2, 4, and 6 hours of drying, respectively (Figure 3). This result was expected since the temperature of 60°C for long periods can lead to microbial thermal inactivation (Yin et al., 2022). In general, it was found that the samples that were immersed in probiotic solution for 30 minutes and processed by US presented the highest counts during drying ($p<0.05$). Another important point to highlight is that, according to the drying kinetics data (Figure 2 and Table 1), convective drying of sonicated guava slices occurred more quickly compared to non-sonicated samples, reaching a moisture content below 25% in up to 4 hours. Thus, drying of sonicated samples can be stopped after 4 hours of dehydration, resulting in counts > 6 log $CFU.g^{-1}$. Therefore, the results indicate that the ultrasound treatment can significantly accelerate the drying of samples and, consequently, maintain higher viability of *L. rhamnosus* GG in guava slices after convective drying at 60°C.

3.3 Surface color of guava slices during drying

The color of food is one of the main parameters evaluated by consumers that can impact product acceptance. Additionally, in a dehydrated product, color evaluation allows the observation of modifications caused during drying (Martins et al., 2022). Figure 4 presents the results for the L*, a*, and b* parameters for surface color analysis of guava slices during drying at 60 °C after pre-treatments with ultrasound combined with probiotic addition.

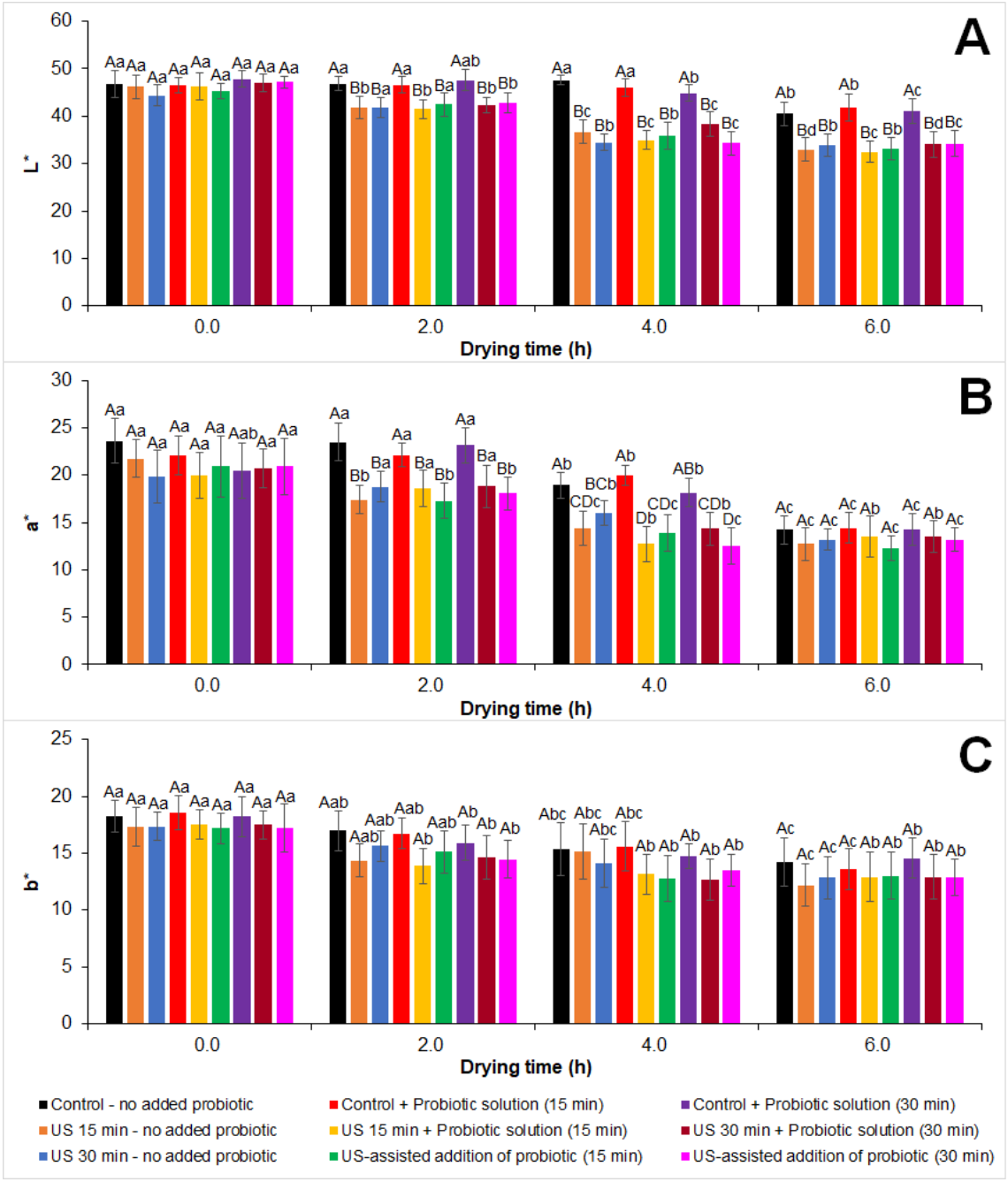


Figure 4. Surface color (A: parameter L*; B: parameter a*; C: parameter b*) of guava slices during drying at 60 °C after pre-treatment by US and probiotic addition. Different uppercase letters indicate significant differences between the different treatments in the same drying time by the Tukey's test at 5% ($p > 0.05$) and different lowercase letters indicate significant differences between the different drying times in the same treatment by the same test.

In general, it was found that the color parameters (L*, a*, and b*) were not affected by the pre-treatments before drying (time 0h) ($p<0.05$) (Figure 4). On the other hand, during drying, reductions in the values of L*, a*, and b* were observed, and the samples processed by US had a greater reduction in the L* and a* parameters (Figure 4). This means that during

drying, there was a reduction in the luminosity (reduction in L*) and in the intensity of the reddish color of these samples, indicating an expected consequence of the drying process (Kek et al., 2013; Nowacka et al. 2017; Rojas et al., 2020b; Martins et al., 2022), which may be due to the high temperature applied for a long period, as well as the removal of water from the plant tissues, contributing to the darkening of the samples.

The L*, a*, and b* parameters were used to calculate the total color difference (ΔE) (Table 2), which describes the general changes in relation to a reference sample (control sample – without US treatment and without probiotic addition). Based on these values, no difference was observed among the samples after the treatments, whether through the application of US or probiotic addition. However, these samples showed ΔE values greater than 2.7 compared to the reference sample. According to the interpretation by Choi et al. (2002), ΔE values greater than 2 confirm a visible color difference between samples. Therefore, based on the obtained values, it is possible to suggest that regardless of the applied treatment, consumers would be able to perceive differences in the color of the samples after the treatments.

Table 2. Total color difference (ΔE) of guava slices during drying at 60 °C after pre-treatment by US and probiotic addition.

Sample (US pre-treatment + Probiotic addition)	**Total color difference (ΔE)**			
	Drying time (h)			
	0.0	**2.0**	**4.0**	**6.0**
Control - no added probiotic	REF*	2.9 ± 1.1^{Bc}	5.9 ± 1.8^{Bb}	12.3 ± 2.1^{Ba}
US 15 min - no added probiotic	3.7 ± 1.8^{Ad}	9.1 ± 2.1^{Ac}	14.3 ± 2.8^{Ab}	18.7 ± 3.1^{Aa}
US 30 min - no added probiotic	5.1 ± 2.9^{Ab}	7.8 ± 1.2^{Ab}	15.2 ± 1.5^{Aa}	17.6 ± 2.1^{Aa}
Control + Probiotic solution (15 min)	2.7 ± 1.9^{Ac}	3.2 ± 0.5^{Bbc}	5.2 ± 1.5^{Bb}	11.8 ± 2.0^{Ba}
US 15 min + Probiotic solution (15 min)	5.0 ± 1.8^{Ac}	8.8 ± 1.8^{Ab}	17.0 ± 2.7^{Aa}	18.4 ± 2.7^{Aa}
US-assisted addition of probiotic (15 min)	4.2 ± 2.5^{Ac}	8.8 ± 1.7^{Ab}	15.8 ± 2.6^{Aa}	18.6 ± 2.6^{Aa}
Control + Probiotic solution (30 min)	4.6 ± 1.7^{Ac}	3.8 ± 1.2^{Bc}	7.1 ± 1.5^{Bb}	11.9 ± 2.1^{Ba}
US 30 min + Probiotic solution (30 min)	3.9 ± 1.5^{Ad}	7.9 ± 1.8^{Ac}	14.0 ± 2.1^{Ab}	17.3 ± 2.7^{Aa}
US-assisted addition of probiotic (30 min)	4.2 ± 2.0^{Ac}	8.1 ± 2.2^{Ab}	17.4 ± 3.1^{Aa}	17.3 ± 2.6^{Aa}

REF*: Reference. Different uppercase letters (column) indicate significant differences between the different treatments in the same drying time by the Tukey's test at 5% ($p > 0.05$) and different lowercase letters (line) indicate significant differences between the different drying times in the same treatment by the same test.

During drying, these differences were significantly accentuated (reaching values of up to 18.6), with the most pronounced effects observed in samples pre-treated with US ($p<0.05$).

These results were expected, considering the thermal impact during drying on the product color. Similarly, in the study conducted by Kek et al. (2013), dehydrated guavas pre-treated with US showed ΔE values of 25. Furthermore, due to faster drying in samples pre-treated by US, more significant color changes were also expected in these samples.

To illustrate these differences in the appearance of the samples, Figure 5 presents images of the samples during drying at 60°C. From these images, it is clear the difference in color, aspect, shape, and size of the samples pre-treated with US compared to the samples not pre-treated with US. These differences are mainly due to the acceleration in the drying process of these samples compared to the samples not pre-treated with US, which contributed to the formation of a sample with smaller size, darker color, and dehydrated aspect and shape.

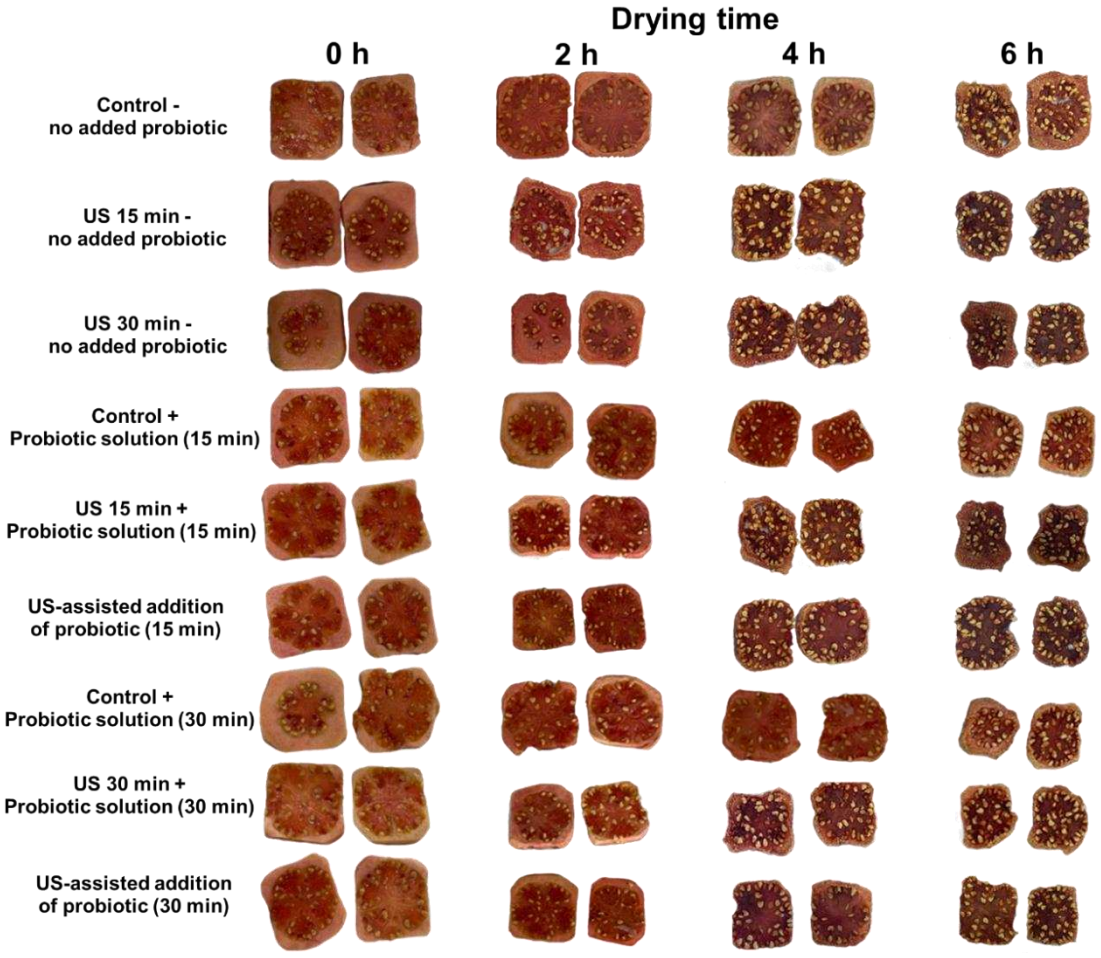


Figure 5. Influence of pretreatments by US and probiotic addition on the appearance of guava slices during drying at 60°C.

3.4. Functional quality of guavas during drying: Vitamin C content, phenolic compounds, and antioxidant capacity

Table 3 shows the results obtained for the functional quality (vitamin C content, phenolic compounds, and antioxidant capacity) of guava slices during drying. Regarding

vitamin C content, it was found that there were no significant differences between the samples pre-treated by US and/or supplemented with probiotics compared to the control samples, regardless of the drying time evaluated ($p<0.05$). However, throughout the drying process, a reduction in vitamin C content was observed in all samples, with reductions ranging from 15% to 23% after 4 hours of drying and from 45% to 52% after 6 hours of drying at 60°C.

Considering that US pre-treatment was able to significantly reduce the drying time of the samples, i.e., from 6 h to 4 h compared to the control samples, it was found that the samples pre-treated by US showed vitamin C losses of 15-20% after 4 h of drying, while the samples without US pre-treatment needed to be dried for 6 hours, reaching reduction levels of 51-52%. Thus, US pre-treatment may be a promising strategy to reduce vitamin C loss during drying.

It is worth noting that vitamin C is an important component with antioxidant properties found in many foods, including guava (Santos et al., 2020). The reduction in vitamin C content observed in this study is consistent with other reports in the literature (Kek et al., 2013). In this case, these authors suggest that the addition of ascorbic acid during processing may be a strategy to compensate for vitamin C loss during drying (Kek et al., 2013).

Regarding the total phenolic compounds (Table 3), no differences were observed in the content of these compounds among the evaluated samples before drying, showing that the US pre-treatment or the probiotic addition did not impact this parameter after processing ($p>0.05$). On the other hand, during the drying of guava slices at 60°C, a reduction of phenolic compounds was observed in all samples, which was expected due to thermal degradation (Nunes et al., 2016). However, the results showed that the samples pre-treated by US had a lower reduction (maximum of 41% and 60% after 4h and 6h, respectively) compared to the control samples not pre-treated by US (maximum of 64% and 81% after 4h and 6h, respectively), regardless of the addition of *L. rhamnosus* GG ($p<0.05$). This result is interesting and is possibly due to the increase in cell permeability promoted by US, which facilitates the release and extraction of these compounds (Gualberto et al., 2021).

Table 3. Vitamin C content, total phenolic content (TPC), trolox equivalent antioxidant capacity (AC) using the ABTS method of guava slices during drying at 60 °C after pre-treatment by US and probiotic addition.

Sample (Pre-treatment + Probiotic addition)	Vitamin C content (mg/100g DM)			Total Phenolic Content (mg GAE/g DM)			Antioxidant Capacity (µmol TE/g DM)		
	Drying time			Drying time			Drying time (h)		
	0 h	4 h (Loss %)	6 h (Loss %)	0 h	4 h (Loss %)	6 h (Loss %)	0 h	4 h (Loss %)	6 h (Loss %)
Control - no added probiotic	557 ± 20^{a}	429 ± 23^{a} (23%)	275 ± 25^{a} (51%)	8.3 ± 0.2^{a}	3.1 ± 0.1^{d} (63%)	1.6 ± 0.1^{d} (81%)	50.2 ± 2.5^{a}	25.1 ± 0.7^{d} (50%)	19.4 ± 0.8^{d} (61%)
US 15 min - no added probiotic	551 ± 26^{a}	454 ± 37^{a} (18%)	289 ± 26^{a} (48%)	8.5 ± 0.1^{a}	5.0 ± 0.2^{c} (41%)	3.4 ± 0.2^{c} (60%)	50.7 ± 1.3^{a}	27.0 ± 0.5^{c} (47%)	22.3 ± 0.8^{c} (56%)
US 30 min - no added probiotic	556 ± 12^{a}	459 ± 21^{a} (17%)	296 ± 22^{a} (47%)	8.5 ± 0.1^{a}	6.1 ± 0.2^{b} (28%)	4.5 ± 0.1^{b} (47%)	50.1 ± 1.3^{a}	29.4 ± 0.7^{b} (41%)	23.5 ± 0.4^{b} (53%)
Control + Probiotic solution (15 min)	560 ± 23^{a}	429 ± 17^{a} (23%)	268 ± 22^{a} (52%)	8.3 ± 0.1^{a}	3.0 ± 0.1^{d} (64%)	1.6 ± 0.2^{d} (81%)	51.0 ± 2.5^{a}	25.7 ± 0.5^{d} (50%)	19.9 ± 0.5^{d} (61%)
US 15 min + Probiotic solution (15 min)	560 ± 26^{a}	450 ± 34^{a} (20%)	287 ± 23^{a} (49%)	8.4 ± 0.1^{a}	5.1 ± 0.1^{c} (39%)	3.4 ± 0.2^{c} (59%)	50.8 ± 1.3^{a}	27.1 ± 0.5^{c} (47%)	22.0 ± 0.5^{c} (57%)
US-assisted addition of probiotic (15 min)	562 ± 24^{a}	466 ± 21^{a} (17%)	295 ± 24^{a} (47%)	8.5 ± 0.3^{a}	6.1 ± 0.1^{b} (28%)	4.7 ± 0.2^{b} (45%)	51.4 ± 1.8^{a}	29.6 ± 0.5^{b} (42%)	23.4 ± 0.6^{b} (54%)
Control + Probiotic solution (30 min)	559 ± 19^{a}	445 ± 30^{a} (20%)	275 ± 27^{a} (51%)	8.2 ± 0.2^{a}	3.1 ± 0.1^{d} (62%)	1.6 ± 0.3^{d} (80%)	50.8 ± 1.5^{a}	25.6 ± 0.9^{d} (50%)	19.9 ± 0.9^{d} (61%)
US 30 min + Probiotic solution (30 min)	561 ± 15^{a}	457 ± 18^{a} (19%)	286 ± 17^{a} (49%)	8.5 ± 0.3^{a}	6.0 ± 0.3^{b} (29%)	4.4 ± 0.3^{b} (48%)	51.3 ± 2.9^{a}	29.5 ± 0.6^{b} (42%)	23.5 ± 0.4^{b} (54%)
US-assisted addition of probiotic (30 min)	558 ± 27^{a}	476 ± 30^{a} (15%)	305 ± 28^{a} (45%)	8.3 ± 0.2^{a}	7.0 ± 0.2^{a} (16%)	5.5 ± 0.1^{a} (34%)	51.0 ± 1.2^{a}	31.5 ± 0.5^{a} (38%)	25.4 ± 0.6^{a} (50%)

The vitamin C content was expressed as mg per 100 g of dry matter (mg/100g DM). TPC content was expressed as mg gallic acid equivalents (GAE) per g of dry matter (DM) - (mg GAE/g DM). Antioxidant Capacity was expressed as µmol Trolox equivalents (TE) per g of dry matter (DM) - (µmol TE/g DM) using ABTS method. Different lowercase letters in the same column indicate statistically significant differences among different treatments by the Tukey's test at 5% ($p<0.05$).

In addition, the results show that US-assisted processes or longer sonication times (30 min) resulted in lower losses of these compounds compared to control samples or samples with shorter US times (15 min) ($p<0.05$). This result indicates that the ultrasonic process time has a significant effect on the quantification of total phenolic compounds, possibly due to greater extraction of these compounds or better efficiency during probiotic addition. Finally, it is important to note again that due to the acceleration of the drying process, US pre-treated samples can be dried for a period of 4h, while control samples (not pre-treated by US) need to be dried for 6h, which directly impacts on a greater loss of these compounds.

Regarding the antioxidant capacity measured by the ABTS radical, the results showed a similar behavior to that obtained for the total phenolic compounds, i.e., initially, no differences in antioxidant activity were observed among the samples ($p<0.05$), with reductions throughout drying for all of them. In this case, the control samples (not pre-treated by US) showed the highest reductions (up to 50% and 61% after 4 and 6 hours of drying, respectively) compared to the sonicated samples (maximum losses of 47% and 56% after 4 and 6 hours of drying, respectively), regardless of the presence of probiotic. Again, the US-assisted or sonicated samples for longer time (30 min) showed lower losses in antioxidant capacity compared to the sonicated samples for shorter time (15 min). These results are compatible with the data obtained for the total phenolic compounds, indicating that these compounds are one of the main responsible for the antioxidant activity of this fruit (Nunes et al., 2016).

Therefore, based on the results obtained, it was found that the reduction in drying time of guava slices provided by ultrasonic pre-treatment contributed to minimizing the thermal impact on the viability of the probiotic, as well as maintaining the functional compounds of this fruit. It is worth noting that the addition of probiotic assisted by US and for longer periods (30 min) positively affected the quantification of functional compounds (especially phenolic compounds and antioxidant activity), showing this to be the best processing strategy for potentially probiotic dried guava production.

4. Conclusion

Based on the results obtained, ultrasonic pre-treatment can significantly reduce the drying time of guava. This result was fundamental for an improvement in the product's overall quality, including greater viability of *L. rhamnosus* GG and better functional quality. Among the treatments studied, the addition of the probiotic assisted by US or longer sonication times

(30 min) were important to minimize the loss of probiotic viability and, mainly, in the functional compounds studied (highlighting phenolic compounds and antioxidant activity).

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CONCLUSÕES GERAIS

Este estudo investigou o efeito do pré-tratamento ultrassônico na aceleração da secagem de goiaba adicionada de *L. rhamnosus* GG e o impacto na viabilidade do probiótico, bem como nos compostos funcionais durante a secagem do produto. Os resultados foram promissores e mostraram que o pré-tratamento por US melhorou significativamente a taxa e o tempo de secagem das amostras, permitindo que a viabilidade do probiótico fosse mantida em níveis elevados após a secagem. Além disso, as amostras pré-tratadas por US apresentaram menores reduções nos compostos funcionais em comparação com as amostras controle. Portanto, o pré-tratamento US pode ser considerado como uma estratégia promissora para produzir goiaba desidratada potencialmente probiótica com melhor qualidade funcional.