CURCUMIN: AN EMERGING TREND IN FOOD DECONTAMINATION

Ana Caroline Romão da Silva[1], Jéssica Ariane Oliveira da Costa Amaral[1], Lenilton Santos Soares[2], Marieli de Lima[1]

[1]Federal University of Uberlândia, Patos de Minas – MG, Brazil (anacrrs@gmail.com)
[2]Federal University of Western Bahia, Barra – BA, Brazil

ABSTRACT: The contamination of products by pathogenic microorganisms is a problem faced by the food industry, which can affect their safety and cause severe poisoning. Thereforeseveral thermal and non-thermal technologies have been used to decontaminate food over the years. Non-thermal methods, mainly photodynamic therapy (which uses ultraviolet (UV) light in the UV-A and UV-C spectrum), have been studied in combination with other techniques and photosensitizers. These methods have commonly been investigated in combination with other technologies and compounds that can enhance their effect. This is the case of curcumin, a carotenoid known for several therapeutic properties, a beneficial impactwhich has been shown beneficial effects in decontamination of food surfaces. Therefore, this integrative review aimed to group current data from the literature on the use of curcumin in food decontamination. To this end, a survey of studies was carried out with the following descriptors in health sciences (DeCS): "curcumin," "meat," and "decontamination." And keywords: “food” and “photodynamic”. It was observed that curcumin has very promising potential as a photosensitizer, as it is capable of significantly reducing the number of microorganisms in several samples and inhibiting their growth. These data show the possibility of using these methods, as they can improve the quality and increase the shelf life of these foods. Finally, studies are still needed applied on a larger scale and find ways to decontaminate foods of different geometries, sizes, and structures.

KEYWORDS: *Curcuma longa*; decontaminants; photosensitizer; photodynamic therapy

1 INTRODUCTION

Every year, about a third of the food produced in the world is lost or wasted. Losses can occur at any stage of the production chain, and one of the main concerns is inadequate storage conditions, causing microbiological contamination (FAO, 2019).

An industry concern is the occurrence of food and water-related diseases. These, even today, continue to be major global problems that cause a significant social and economic impact (Newell et al., 2010; WHO, 2022).

Non-thermal technologies have gained prominence in recent years as an alternative to conventional technologies. They reduce the microbial load while maintaining the food's sensory properties. Antimicrobial photodynamic therapy, which is ultraviolet light-based processing for food decontamination, is one such process. (Bhavya and Hebbar 2017; Baltazar et al., 2015).

Non-thermal methods have been studied in combination with other techniques and with the use of photosensitizers to enhance their results. Incorporating these technologies in the food industry minimizes the unwanted effects of conventional methods on bioactive compounds in vegetables and their products (Khan et al., 2018; Liao et al., 2020).

Ultraviolet (UV) light comprises the UV-A and UV-C spectra and has been studied for its effectiveness against pathogens and spoilage microorganisms in water and wastewater, on surfaces, in the air, and in food (Zhao et al., 2019; Rosario et al., 2021; Soro et al., 2022).

Curcumin is an antioxidant known worldwide for its therapeutic properties, extracted from *Curcuma longa* L. (Mahmoud et al., 2017). Its photosensitizing characteristics against a wide range of microorganisms, such as Gram-positive bacteria, Gram-negative bacteria, viruses, yeasts, and molds, have been studied and reported by several authors, demonstrating promising inactivation efficiency (Correa et al., 2020; Chen et al., 2020; Gao et al., 2023).

On the other hand, despite being considered a potentiating agent in the decontamination of various foods and a natural compound with excellent biocompatibility, curcumin's antimicrobial photodynamic efficacy is limited due to poor adhesion to the cell walls of Gram-negative bacteria, low photostability, and limited solubility in water (Spaeth et al., 2018).

According to Saraiva et al. (2024a), curcumin-mediated photodynamic therapy is a promising method to inhibit foodborne bacterial pathogens, allowing better food safety and preventing the development of multidrug resistance in microorganisms. However, given the reported barriers, such as that curcumin's hydrophobicity, which impaired its solubility in milk, this decontamination method is more appropriate as a complement to traditional technologies.

In this context, this review aimed to group current data from the literature on the use of curcumin in food decontamination.

2 METHODS

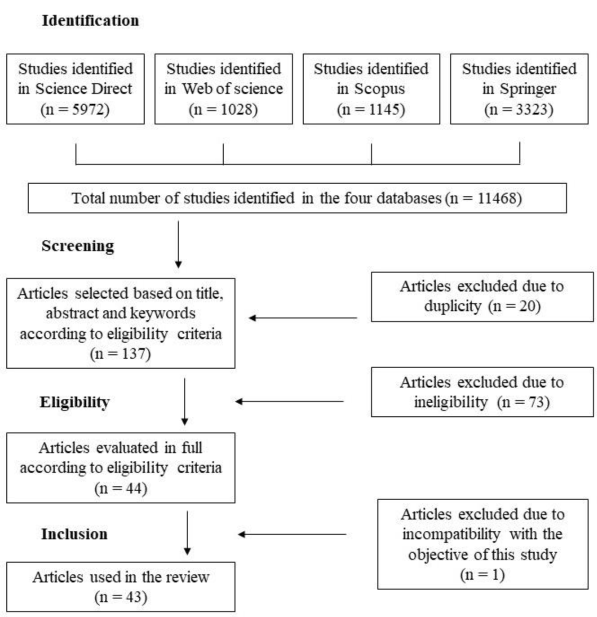
This study is bibliographical research with a qualitative and exploratory approach. An integrative literature review was conducted, surveying studies in the following databases: Web of Science, Science Direct, Scopus, and Springer.

To carry out the searches, the following descriptors in health sciences (DeCS) were used: "curcumin," "meat," and "decontamination," and the keywords: "food," and "photodynamic." Furthermore, to optimize searches, the Boolean operator “AND” was used to combine the term “curcumin” with other terms.

The inclusion criteria were complete scientific articles published in the last five years, available in English, with full text, that addressed the topic of decontamination in food using curcumin as a photosensitizer. Review articles and studies that use curcumin in other areas, articles outside the period studied, and incomplete works were excluded from the sample.

Figure 1 shows the flowchart of the search in the databases, demonstrating all stages of the research.

Figure 1. Literature review flowchart.



Source: Author (2023).

3 DISCUSSION

Various food decontamination techniques are employed in the industry to inactivate or physically remove microorganisms from different food matrices. Reducing microbial viability can result in extending the shelf life of food, increasing its shelf life (Ma et al., 2017), and preserving nutritional qualities over time (Qiu et al., 2019).

Among these, non-thermal technologies have demonstrated great potential in product decontamination. One is antimicrobial photodynamic therapy, a promising emerging technology that could alleviate the microbial challenges facing food systems (Cossu, Ledda, and Cossu, 2021; Zhu et al., 2021). It uses molecules (photosensitizers) that absorb energy from UV-Vis light (Kalb et al., 2023) and act to create reactive oxygen species (ROS), exposing photosensitizers to visible light to activate them (Glueck et al., 2017). Eventually, cells and biomolecules are oxidized and destroyed (Penha et al., 2017).

In this technology, excited photosensitizing molecules transfer excess protons/electrons or energy to surrounding substances, generating ROS. These oxidize the cell membrane components, proteins, and nucleic acids, leading to apoptosis. It is important to highlight that ROS have an extremely short half-life and cause non-specific damage to bacterial cells, which makes it difficult for bacteria to activate defense systems or develop resistance to photoinactivation (Jia et al., 2019; Chai et al., 2021).

The study by Saraiva et al. (2024b) attributed the reduction of *Pseudomonas fluorescens* in milk to the production of reactive oxygen species that led to the death of the studied microorganism. This is a fact corroborated by another study, where Saraiva et al. (2024a) observed that curcumin could generate highly toxic and deadly ROS for photodynamic inactivation of high microbial loads.

Several photosensitizers have been applied in this decontamination technology. Among these, curcumin has been gaining more and more attention due to its high efficiency and low toxicity (Dias et al., 2020). Its maximum absorption peak occurs in blue light at 430 nm. And although studies have shown that this wavelength does not have high penetration into biological tissue, the use of this compound is ideal for disinfecting surfaces and treating superficial injuries, demonstrating lethality even for pathogenic microorganisms (Corrêa et al., 2020; Picco et al., 2019; Xie et al., 2022).

Curcumin is a bioactive compound extracted from the rhizome of *Curcuma longa L.*, a plant belonging to the Zingiberaceae family. It has been studied for many years due to its therapeutic properties, such as antioxidant, antimicrobial, and anti-inflammatory properties (Arshad et al., 2018; Ashraf et al., 2018). Furthermore, it has been widely used as a non-toxic additive in the field of food processing and the production of biofilms (Abdoua, Galhoumb, and Mohamed, 2018; Corrêa et al., 2020).

In research by Damyeh et al. (2019), curcumin-based photosensitization exhibited promising antimicrobial efficacy against a wide range of food spoilage microorganisms, resulting in increased shelf life with minimal adverse effects on the quality criteria of the treated foods. Furthermore, this carotenoid has proven practical, safe, and resistant to lighting. Overall, it can be considered an alternative to current decontamination techniques, with the potential to be applied on an industrial scale.

Ayyat et al. (2018), when evaluating the effects of dietary supplementation with food additives in alleviating the harmful impacts resulting from aflatoxin B1 toxicity in Nile tilapia, observed that the curcumin-enriched diet was one of the candidate treatments to reduce the harmful effect of aflatoxin toxicity. This is because, according to Nayak and Sashidhar (2010), this bioactive compound can reduce the toxicity of these metabolites, modulating the microsomal activation of aflatoxin and increasing its detoxification.

According to Saraiva et al. (2021), ,curcumin can reduce bacterial counts and proteolysis in cheeses, in addition to preserving greater hardness and chewiness of the product. Furthermore, its antimicrobial effect is enhanced when used as a photosensitizer in the photodynamic inactivation of microorganisms. On the other hand, it is important to observe the surface of the product studied, which can hinder the photoinactivation of microorganisms.

In chickens, a study by Gao et al. (2023) showed that photodynamic treatment using curcumin as a photosensitizer did not negatively influence any of the microbiological factors evaluated. In the long term, inhibition of *L. monocytogenes* and Salmonella growth was observed in chicken skin under refrigerated storage conditions. Thus, microbial photoinactivation with curcumin was demonstrated to be equivalent to or better than treatment with 300 ppm peracetic acid. Also, according to the authors, the results found are encouraging and suggest that curcumin has potential application in the treatment of poultry carcasses and parts to improve microbial safety.

Santos et al. (2019) investigated the ideal parameters of photodynamic therapy for the in vitro inactivation of *S. aureus* and its application in the decontamination of coalho cheese using a water-soluble curcumin salt. And according to the authors, this technique can potentially be an auxiliary strategy to thermal techniques (for example, pasteurization) to overcome recontamination due to poor storage conditions and inappropriate handling.

In chilled pork, a study guided by Wu et al. (2023) showed that photodynamic therapy associated with curcumin could extend the product's shelf life from 4–5 days to 10 days. Also, according to the authors, this technology was an effective way to reduce the total bacterial count of meat during refrigerated storage, delaying spoilage and significantly extending its shelf life.

Curcumin has also been studied in the decontamination of meat from different animal species, such as beef (Côrrea et al., 2020; Herculano et al., 2022; Lu et al., 2023), chicken (Côrrea et al., 2020; Gao and Matthews, 2020; Gao et al., 2023) and salmon (Chen et al., 2023), demonstrating promising results with significant effects on microbial reduction.

Table 1 presents studies regarding using curcumin as a photosensitizer in the decontamination of various foods using photodynamic techniques. The works were ordered according to the year of publication to appreciate the evolution of the subject over time.

Table 1. Research was carried out using curcumin or curcuminoids to decontaminate food through photodynamic therapy.

Material	Microbial reduction	Reduced microorganism	Author
Hydrogel coatings	> 4 log $CFU.ml^{-1}$	*L. innocua*	Tosati et al. (2018)
In vitro	4 log $CFU.ml^{-1}$	*Burkholderia cepacia*	Hu et al. (2018)
In vitro	2 log $CFU.ml^{-1}$	*E. coli*	Aurum and Nguyen (2019)
In vitro	3 log $CFU.ml^{-1}$	*Aspergillus flavus*	Damyeh et al. (2019)
Coalho cheese	4.34 log $CFU.ml^{-1}$	*Staphylococcus aureus*	Santos et al. (2019)
Hami melon	~1.8 log $CFU.g^{-1}$	Total aerobic microorganism count	Lin et al. (2019)
Biofilm	> 4 Log $CFU.ml^{-1}$	*L. monocytogenes*	Huang et al. (2020)
Pear	> 3.2 log $CFU.ml^{-1}$	*E. coli*	Corrêa et al. (2020)
Sliced cheese	3.65 log $CFU.g^{-1}$	*L. monocytogenes*	Park and Há (2020)
Pineapple	1.70 log $CFU.ml^{-1}$	*E. coli*	Bhavya et al. (2021)
	1.78 log $CFU.ml^{-1}$	*Staphylococcus aureus*	
Fresh-cut potato slices	2.43 log $CFU.ml^{-1}$	*E. coli*	Yu et al. (2021)
	3.18 log $CFU.ml^{-1}$	*Staphylococcus aureus*	
Fresh millet dough sheet	~ 1 log $CFU.ml^{-1}$	*Staphylococcus saprophyticus*	Wang et al. (2021)
Pineapple	1.24 log $CFU.ml^{-1}$	*E. coli*	Zou et al. (2021)
In vitro	2.3 log $CFU.ml^{-1}$	*Aspergillus flavus*	Nguenha et al. (2022)
Streptococcus mutans e *Candida albicans* biofilm	> 5 log $CFU.ml^{-1}$	*Streptococcus mutans* and *C. albicans*	Santos et al. (2022)
Gelatin/chitosan-based biofilm	4 log $CFU.g^{-1}$	*Staphylococcus aureus*	Dias et al. (2022)
Gelatin/chitosan-based biofilm	> 4.5 Log $CFU.ml^{-1}$	*Listeria monocytogenes*, *Escherichia coli* and *Shewanella putrefaciens*	Wang et al. (2022)
In vitro	> 6 log $CFU.ml^{-1}$	*Shigella flexneri*	Liang et al. (2022)
Peanut	2 log $CFU.ml^{-1}$	*A. flavus*	Mukubesa et al. (2022)
Biofilm	2.03 log $CFU.ml^{-1}$	*S. aureus*	Ribeiro et al. (2022)
In vitro	4.88 log $CFU.ml^{-1}$	*Bacillus subtilis*	Dong et al. (2022)
In vitro	4.0 log $CFU.ml^{-1}$	*Botrytis cinerea*	Seididamyeh et al. (2023)
In vitro	> 6 log $CFU.ml^{-1}$	*L. monocytogenes* *Salmonella enterica*	Kalb et al. (2023)
In vitro	5 log $CFU.ml^{-1}$	*S. aureus*	Crugeira et al. (2023)
In vitro	4.5 log $CFU.ml^{-1}$	*S. aureus*	Dias et al. (2023)
Fresh-cut orange	3.23 log $CFU.ml^{-1}$	*Penicillium italicum*	Wang et al. (2023)

In vitro	7 log CFU.ml^{-1}	*Staphylococcus aureus*	Saraiva et al. (2024a)
Milk	1.63 log CFU.ml^{-1}		
In vitro	7 log CFU.ml^{-1}	*Pseudomonas fluorescens*	Saraiva et al. (2024b)
Milk	0.96 log CFU.ml^{-1}		

Source: Author (2023).

3.1 Curcumin in biofilm decontamination

Huang et al. (2020) demonstrated that photodynamic inactivation using curcumin negatively altered the architectural structure and markedly reduced the adhesion capacity of biofilms, resulting in highly efficient eradication. The study also showed that the target of attack of the treatment was the cytoplasmic DNA and protein, and not the outer membrane of *L. monocytogenes* cells. This fact caused a reduction in the expression of virulence genes and in the bacteria's ability to adhere, invade, and escape.

In an investigation into the antibacterial effects on the photodynamic inactivation of *Burkholderia cepacia* by curcumin in combination with EDTA, bacterial morphological changes and extravasation of intracellular contents were observed after photodynamic treatment. There was also cleavage of genomic DNA and a general loss of bacterial proteins attributed to large-scale protein degradation following photodynamic inactivation treatment (Hu et al., 2018). Wan et al. (2022) also observed extravasation of DNA and intracellular substances. Lu et al. (2023) observed damage to the cellular morphology of the bacteria *Brochothrix thermosphacta* and *Pseudomonas lundensis*.

3.2 Application in industry

Chen et al. (2020) associated polyvinyl acetate with curcumin in manufacturing photoactive coatings for fresh pork packaging. Regarding *S. typhimurium* or *S. aureus*, the investigation into the biocidal activity of the coatings showed it to depend on the concentration of curcumin, and the lethal effect increased with the irradiation time. Characteristic also observed by Wang et al. (2022) studying a gelatin/chitosan-based biofilm for food packaging. In this study, the inactivation effect was enhanced with increasing curcumin concentration and lighting time.

On the other hand, Gao and Matthews (2020) observed that incubation time and light dose do not appear to influence the antimicrobial activity of the water-soluble photosensitizing curcumin, suggesting that photoinactivation can be achieved quickly. This factor is crucial in developing a rapid antimicrobial intervention to meet the fast line speeds used in the poultry industry.

According to Dias et al. (2022), physically incorporating photosensitizing molecules, such as curcumin, is an efficient approach to preparing photo antimicrobial films. In this study, greater heterogeneity was also observed, probably associated with the greater hydrophobicity of curcumin and its lower solubilization in the ethanolic solution compared to pomegranate peel extract.

4 CONCLUSIONS

Curcumin has very promising potential as a decontaminant, as it can significantly reduce the number of microorganisms in several samples and inhibit their growth for some time. These data show the potential of photodynamic therapy associated with photosensitizers, as they can improve the quality and increase the shelf life of these foods. Finally, studies are still needed to apply the technology on a larger scale and to find ways to decontaminate foods of different geometries, sizes, and structures.

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