Available online at www.sciencedirect.com

ScienceDirect

Current Opinion in Food Science

Cold plasma: background, applications and current trends

Shashi K Pankaj and Kevin M Keener

Cold plasma technology offers several potential applications in the food and biomedical industries. This work aims at highlighting the potential applications of cold plasma in food industry highlighting the current research and trends in this area. The main applications of cold plasma for food industry could be grouped as food decontamination, food quality improvement, toxin degradation and surface modifications of packaging materials. Cold plasma has proven to be effective for inactivation of various pathogens and spoilage organisms without adversely affecting the food quality. It has also shown the potential for significant degradation of mycotoxins and pesticides present in the agricultural produce. Current plasma research is driven to analyze its effectiveness against various pathogens in different food products with a keen emphasis to gain insights on the inactivation mechanisms at a molecular level. Although, cold plasma technology has shown promising results, it requires further studies to understand the reactive gas chemistry, toxicological, ecological and economic impacts of this technology.

Address
Center for Crops Utilization Research, Iowa State University, Ames, IA 50011, USA

Corresponding author: Keener, Kevin M (kkeener@iastate.edu)

Current Opinion in Food Science 2017, **16**:49–52

This review comes from a themed issue on **Innovation in food science**

Edited by **Nuria Acevedo**

http://dx.doi.org/10.1016/j.cofs.2017.07.008

Introduction

Cold plasma is a novel non-thermal technology, which has shown significant potential for applications in food industries. Earlier, cold plasma was widely used mainly in the polymer and electronic industry for surface modification and functionalization of different polymers. However, in recent years, the applications of cold plasma has rapidly expanded into treatment of biomedical devices and biological materials, including foods [1••].

The term 'plasma' refers to a quasi-neutral ionized gas, primarily composed of photons, ions and free electrons as well as atoms in their fundamental or excited states with a net neutral charge [2]. Plasma is generally categorized as 'thermal' when electrons and other gas species are in thermodynamic equilibrium and 'non-thermal' when they exist in non-equilibrium. Earlier, cold plasma were generated under low-pressure conditions limiting its applications. However, recent advances in plasma engineering have allowed cold plasma generation at atmospheric pressure leading to increased research on cold plasma at various interfaces of life sciences. A summary of major applications of cold plasma technology is shown in Figure 1.

There are various types of cold plasma generation systems used for different applications in the industry. They could range from corona discharges, microwave plasma, radio frequency plasma, inductively coupled plasma, capacity coupled plasma, electron cyclotron resonance plasma and dielectric barrier discharge plasma. Among these, dielectric barrier discharge and jet plasma are the most used for food research owing to their simple, versatile and adaptive designs and working.

Plasma can be generated in any neutral gas by providing sufficient energy for its ionization making plasma chemistry much more complex. For example, air plasma consists of over 75 unique species and more than 500 chemical reactions happening at nano, micro, milli and seconds time scales [3]. There is a continuing research in the field of plasma chemistry for identification of reactive species generated in the plasma and their interaction with the biological and chemical components of food products. This requires research efforts to understand the mechanisms for microbial inactivation, toxin degradation, or other desirable effects and subsequently leverage such information for food product/process improvement.

Applications of cold plasma

Specifically for the food industry, current cold plasma research are focused on its applications for food decontamination, toxin degradation and packaging modifications which are discussed in the following sections.

Cold plasma for food decontamination

Cold plasma has proven an effective non-thermal processing technology for inactivation of various pathogenic and spoilage microorganisms found in the food products. There are various reviews available in literature on application of cold plasma providing a snapshot of progress of cold plasma technology in food processing [4–8]. Although, most of the current studies are still focused on exploring and optimizing the plasma decontamination process conditions for different food products targeting various microorganisms, there has been a significant interest for understanding the plasma inactivation mechanisms for different microorganisms. It was previously reported that reactive oxygen species play the most crucial role in microbial inactivation leading to strong oxidative stress conditions, causing cell damage by lipid peroxidation, enzyme inactivation and DNA cleavage [9]. Recently, Han *et al.* [10•] have reported different inactivation mechanisms for Gram positive and Gram negative bacteria by cold plasma. They showed that cold plasma inactivation of Gram positive bacteria (*Staphylococcus aureus*) was mainly due to intracellular damage and little envelope damage whereas Gram negative bacteria (*Escherichia coli*) was inactivated mainly by cell leakage and low-level DNA damage. A succint review by Bourke *et al.* [11••] have summarized the interactions of plasma gas species with a range of microbiological targets along with the advances in the mechanistic insights. These studies clearly indicates the selective and differential interactions of reactive gas species in the plasma systems emphasizing the need for future mechanistic studies for better understanding.

Apart from microbial inactivation, effects of cold plasma on the food quality has been another important aspect drawing attention of food researchers. Cold plasma inactivation of food enzymes have received significant attention in this regard. A review by Misra *et al.* [1••] reported that plasma gas species causes loss of secondary enzyme structure due to breakdown of specific bonds or chemical modifications of the side chains and were dependent on power input, degree of exposure, mass transfer between the plasma-liquid phases, structural complexity and stability of the enzymes in their local environment.

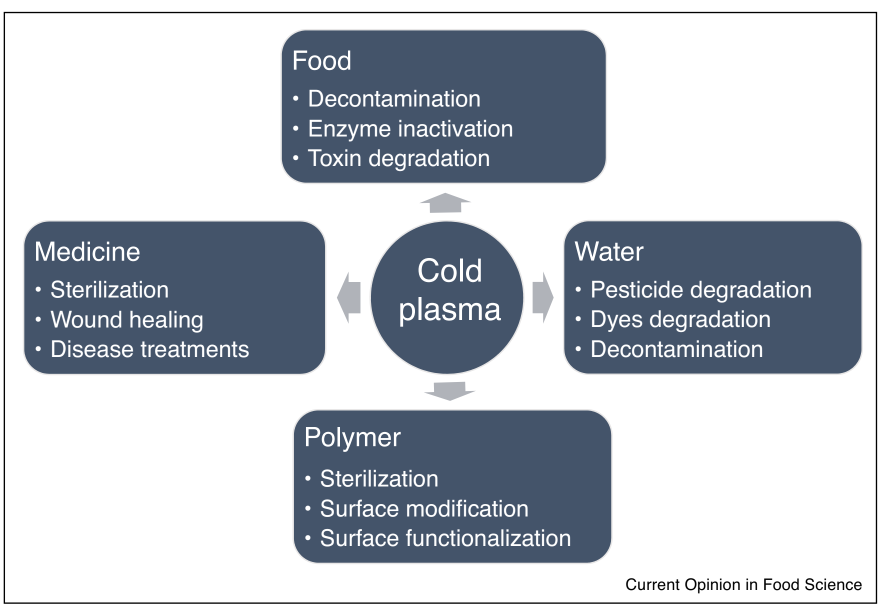
Further research are recommended for identification of plasma generated reactive species and their interaction with potential microorganisms and food components at molecular level for further mechanistic understanding.

Cold plasma for toxin degradation

Natural and synthetic toxins are ubiquitously present in our ecosystem. Toxic compounds such as trypsin inhibitors, saponins, goitrogens, lectins might be inherently present in various food products. Other toxins like pesticides, endocrine disruptors, mycotoxins etc. are also present in our food and water system raising concern for consumer health and safety. Currently, there are very limited non-thermal technologies available for control and degradation of toxic compounds present in food products. Cold plasma has shown promising potential for degradation of various food toxins gaining increased interest from food researchers in past few years. Most of the current research in food products are focused on cold plasma degradation of mycotoxins and pesticides.

Mycotoxins are toxic secondary metabolites produced by filamentous fungi contaminating various food products posing serious health risks problems. Many of the mycotoxins have been classified as carcinogenic, mutagenic and genotoxic. The resistance for degradation of

Figure 1



Summary of major applications of cold plasma technology.