Shockwave an Emerging Technology for Improving Processed Foods Quality: Mini Overview

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ABSTRACT

Shockwave technology is defined as an underwater hydrodynamic pressure, carried out by use of mechanical pressure pulses of water placed in a large tank. The first system used in the 1990s was generated by explosives, or by discharging electrical currents, as a second system underwater. The generated waves are transmitted through water and media in an acoustic match with water. A mechanical stress occurs, causing disruption and tearing of materials, exposed to the transmitted waves, according to their different properties. This new disruptive technology completely changes the way things are done. It is used in food applications to disintegrate tissue, modify the structure of biological materials, enhance extraction of plants bioactive substances, structure modification of grains, improve milling yield, shucking oysters, and improve meat tenderization and shelf-life .Another application is for easy drying to avoid fracture of the biological tissue. This technique also has an impact on food-borne pathogens and spoilage microorganisms in food, where, it is more effective when combined with other hurdles. The use of shockwave as a pretreatment process was also investigated to increase the yield and nutritional value of the extracted juice and oil *via* softening of plant tissues. Shockwaves propagate in plant media generate multiple cracks by underwater shockwaves, which act as permeation pathways, increasing the extraction ratio of essential oils in steam distillation processes. Underwater shockwaves instantly cause high pressure, splitting and open cell structures and accordingly instantly generate multiple cracks on the cell wall. Shockwave pretreatment liquefies vegetable material immediately and destroys cell structures. Some constraints are facing the application of shockwaves on a commercial scale in the food industry. Yet, shockwaves may become tomorrow's processing technology for producing novel great tasting foods and other products while maintaining many natural characteristics of the products.

Keywords: Shockwave, quality, meat tenderization, bioactive components

INTRODUCTION

Shockwave technology is a hydrodynamic pressure process, which is also known as an underwater shockwave processing (USP). It is a mechanical strong pulse of water placed in a tank. The first system of its generation was by use of explosives, as started in the 1990s.The second system used was by discharging electrical currents underwater. The generated waves are transmitted through water and other similar media in a match with water. The strong mechanical pressure disrupts and tears the materials, which are exposed to the transmitted strong waves. The effect of that stress differs according to the properties and nature of the exposed materials. Dapeng *et al.* (1994) calculated the velocity and time of the generated shockwaves by software application using an image-processing system.

Otsuka *et al.* (2006) developed a pressure vessel for food processing by shockwaves, as an application of that emerging technology in the food industry. Higa *et al.* (2012), used underwater discharge as an energy efficiency process as abase for shockwave generation. The effect of the high voltage power supply shockwave and explosion by electrical discharge on the contact materials was evaluated, (Higa *et al.*, 2015 & 2016). Propagation behavior of batch processing shockwave for pressure vessels by numerical simulation was also designed by Shimojima *et al.* (2016).

According to Ken *et al.* (2018), the National Institute of Technology, Okinawa College (OkNCT) has developed a food processing machine that generates underwater shockwaves through wire electrical discharge. The machine can be used for sterilization, milling flour, softening, and extraction of various functional valuable active substances. That new disruptive technology is used in food applications to disintegrate tissue, modify the structure of biological materials, enhance extraction of plants bioactive substances, structure modification of grains, improve milling yield of grains and rice flour (Shimojima *et al.*, 2012 & 2015), and improve meat tenderization. Other applications would be for drying to remove water easily, to avoid fracture of the tissue, according to Ying *et al.* (2020). This technique also has an impact on food-borne pathogens and spoilage microorganisms in food, where, it is more effective to extend the shelf-life of the products when combined with other hurdles.

Commonwealth Scientific and Industrial Research (CSIRO, 2018) is an Australia's national science agency and innovation catalyst, that solves the greatest challenges through innovative science and technology. The CSIRO's Brisbane laboratory is home to the world's second shockwave unit, they use electrical discharges to generate intense shockwaves, which travel through the surrounding liquid at high energy and extremely high .speed to pass through the. Exposed material. According to Josef *et al.* (2020) and Ying *et al.* (2020), USP is a non-thermal food processing method, which does not increase the temperature of the treated commodity or the food product submerged in a liquid. Generally, the use of shockwave applications is to improve the quality, safety, and nutritional aspects of many products, which are of the main aims in the food industry.

The USP as a pretreatment process was found to increase the yield and nutritional value of the extracted juice and oil, through the rupture and softening of the plant tissues. Shockwaves immediately liquefy and cause many cracks in the exposed plant materials, which are considered as pathways in the cell walls. This simultaneously destroys cell structures and accordingly increases the following step of essential oils extraction by steam distillation.

According to Josef *et al.* (2020), the best ways to generate these destructive stress forces are short circuits of high-voltage or wire explosions. That application as an emerging technology is commercially promising for the extraction of essential oils and other highly- price substances of biological origin, despite the high price of the energy requirements. Generally, shockwaves technology is going to be a valuable pretreatment mean for producing novel and high-quality foods and other products with maintaining many of their main characteristics and value.

Meat industry

The shockwave technique has also an impact on food-borne pathogens and spoilage microorganisms in food. Anisha & Morse (2002) investigated the hydrodynamic pressure processing (HDP) in a steel container, as a technology to reduce spoilage microorganisms found in fresh ground beef and roasted beef. The investigated samples were vacuum-packaged for HDP treatment. No pH difference was demonstrated between the control and the HDP-treated meat, just after the treatment. Yet, there was a significant difference ($P<0.05$) in the pH value between the control and HDP-treated meat after storage being at pH 8.2 and 5.6, respectively. On the other hand, there was an immediate reduction in the microbial count just after HDP application, followed by a demonstrated detectable marked difference between the control and the HDP-treated samples after further storage. Accordingly, Anisha *et al.* (2002) stated that with HDP, is a possible useful proper means to reduce spoilage microorganisms found in or on some meat types, ground or pieces, to extend the shelf -life.

Generally, meat tenderization is carried out mainly by either of a biological or a mechanical method. The biological methods are based on the effect of the endogenous and the exogenous proteases. On the other hand, mechanical tenderization depends on the breakage of the muscle structure, by a mechanical mean, as grinding, mincing or hammering. Tomas *et al.* (2013) reported that different methods can be used by the meat industry to improve meat tenderness.

Bolumar *et al.* (2013) reviewed the new developments in shockwave technology intended for meat tenderization and the opportunities and challenges of that application. Nowadays, the most common food applications of USP is currently meat tenderization, to improve the sensory characteristics of meat as a value-added process, particularly in marketing tough cuts of meat. Shockwave technology is considered as a great emerging way of improving meat tenderness and the eating quality of cheap meat cuts, which are generally minced or sold at low prices. That has an important role in the economic value of the meat industry, either as the raw or the processed products. Scientists have found the eating quality of tough cheap cuts of meat like shank, silverside and chuck steak can be improved and instantly tenderized by using shockwave technology. That is considered a driver of profit for farmers. Consumers also look for meat tenderness as an important parameter of the sensory quality of meat (Pittaway, 2018).

The shockwave meat tenderization process, vacuum pack meat muscles or steak-sized meat cuts were placed on a conveyor belt, transferred (*via* the conveyor belt on the shockwave unit into water. According to CSIRO (2018), the tenderization process is instant, and typically a reduction in the toughness of beef of about 15-20 per cent was demonstrated, with no effect on colour and flavour.

The application of hydrodynamic pressure or shockwaves has shown outstanding improvements by reducing the Warner Bratzler Shear Force by 25% or more. However, the technology has not penetrated into the market due to the lack of robustness as an important application to fulfill the industrial requirements. They also described other main challenges for the continuous application of shockwaves and presented improvements on the tenderness of meat by using that novel technology. Zuckerman *et al.* (2013) demonstrated the microscopic changes occurring in the muscles and connective tissue of meat due to HDP. Ken *et al.* (2018), experimentally investigated the conditions for pork food softening. Their results revealed that the softness was related to the distanced shockwave generation point from meat and the number of shockwaves processed.

Shucking oysters

Shucking oysters is the process of opening the shell to reveal the delicate meat inside. The shockwaves can disrupt biological tissues. Accordingly, that technology can also be applied to other foods including shucking oysters. That technology would basically break the shell but leave the meat of the oyster intact inside, according to CSIRO (2018).

Juicing and extraction processes

Ultrasound-assisted extraction is known to have a significant effect on the rates of various processes in the chemical and food industries. Ultrasounds used to attain and complete full extractions in minutes with high reproducibility. Solvent consumption is also reduced by obtaining final products with high yield and purity (Chemata *et al.*, 2017). The effects of ultrasound propagation in solid/liquid media have been described in the literature. The instantaneous HDP control using shockwaves applies to a wide range of extraction processes such as extraction of juices or ingredients from other naturafty occurring foods and medicinal plants, according to Atsushi *et al.* (2018).

Juicing of Yuzu fruit

Japanese Tanaka Yuzu (*Citrus junos*) fruit is a green or yellow aromatic sour citrus fruit, whose acidic rind and juice are often used in the Japanese cuisine. It is also used commercially in the production of sweets, beverages, cosmetics, perfumes, aromatic and similar products. The important bioactive components present in the fruits include vitamin C, β-carotene, flavonoids as antioxidants, limonoids and dietary fiber. Juicing process at high pressure with the traditional methods of juice extraction resulted in a presence of high content of the bitter components. Accordingly, the pressure must be carefully and well-controlled, to obtain fruit juice with a strong aroma with less bittemesss. Kuraya *et al.* (2017) studied the improvement of the juicing process by underwater shockwave pretreatment. Eisuke *et al.* (2017) evaluated the content of the volatile compounds in yuzu juice to investigate whether underwater shockwave pretreatment affects its scent. A shockwave pretreatment at increased discharge and energy of 3.5 kV and 4.9 kJ, respectively, increased the content of aroma-active compounds and afforded about a tenfold increase in the scent intensity of the yuzu juice. The proposed treatment indicated a good performance and broad high reliability for the extraction of the volatile and aroma-active compounds from the yuzu fruits. Accordingly, as this technique for improving the scent of the extracted fruit juice, was demonstrated and confirmed, its potential for application to a wide range of food extraction processes can be evaluated.

Tomato juicing

According to Monabe *et al.* (2011), mixer blending contributes to a concentration of saponin, and esculeoside A, from the extracted tomatoes to be 0.043 and 0.046 %, respectively. On the other hand, the concentration of the two substances obtained by shockwaves, was nearly twice that content; which considered shockwaves application to be very efficient for removing such substances. Besides that other two spirosolane glycosides; namely, tomatine and lycoperoside A, were extracted for the first time from the ripe tomatoesby using shockwaves, while these two compounds were not detected by mixer blending. However, whether these glycosides are produced from esculeoside A or are newly extracted from the plant organ by the shockwave is still unclear. Maehara *et al.*

(2011a) investigated the extraction of ginger and tomato juice by using the underwater shockwave. Efficient improved extraction of tomato saponin using shockwaves was investigated by Manabe *et al.* (2011).

Ruly *et al.* (2019) demonstrated that hydrodynamic cavitation (HC) technology, showed many benefits in many applications in food processing operations, due to its moderate cost and simple configuration. They investigated and evaluated both physical properties and the microbial aspects of the product. The quality and stability of the HC-treated tomato juice showed that significant marked effects were induced dye to cavitation of the HC-treated fruits. The tomato juice showed an increase of the apparent viscosity, and better homogenization stability with no sedimentation as compared with the control. The important functional substances as lycopene and phenolic contents in tomato juice were not altered after HC-treatment. The microbiological quality was also improved, particularly when the treatment was carried out above a temperature of 55 °C. This technology can be recommended for further studies to investigate it as a promising strategy to be applicable for food processing to enhance desirable properties in other juices. Particularly that the desirable functional compounds were not altered due to that mild moderately cost processing conditions. This technology also shows potential improvement of the microbial quality of the processed juices. Accordingly, HC process can be evaluated to be adapted for a considerable improvement in fruit juice quality and stability.

Carrots juicing

Carrots are rich sources of functional compounds as lipophilic antioxidants; namely, carotenoids and xanthophylls,and hydrophilic polyphenols. Fiselava *et al.* (2008), Khandare, *et al.* (2011) and Atsushi *et al.* (2017) demonstrated that pretreatment of carrots with shockwave, significantly increased the juice yield, as well as its carotene, and sugar content. Their results reveal that the shockwave technology is considered a potential means to be applicable in other food extraction processes.

Ginger extraction

Ginger (*Zingiber officinale*) is a worldwide consumed spice, originating from Southeast Asia and spreading to Europe and other Western countries. Maehara *et al.* (2011b) studied a new processing technique of ginger by using underwater shockwave. The extraction efficiency of ginger using shockwave showed good results and improved extraction conditions. The increased extraction efficiency of lipophilic gingerols and shogaols from ginger by shockwaves was also demonstrated. These phenolic compounds are the secondary metabolites of the *Zingiberaceae* family and are responsible for the pungent taste of ginger. They also are used for their wide range of applications due to their numerous pharmacological properties (Qian-Qian, *et al.*, 2019).

Coffee extraction

Takemoto *et al.* (2008), investigated the use of underwater shockwaves to improve thqextract;on of roasted coffee beans. The investigated method was compared with the freeze-drying extraction process. The result indicated that the content of the volatile compounds extracted by shockwaves was excellent and effective. The results of extraction were further confirmed by gas chromatography, to assess the quality of the' roasted coffee bean£ extracts. The aroma and taste of the coffee beans are related mainly to the extracted volatile compounds. Accordingly, the quality of coffee beverages and their overall acceptance is improved.

Some previous studies indicated that water pressure is one of the main important factors which influence the sensory quality of espresso coffee (EC). Andueza *et al.* (2003) studied that effect on the final quality of Arabica ECs and classify ECs prepared at different pressures according to their physicochemical and sensory properties like foam, taste characteristics, some key odorants and flavour compounds. Arabica ECs prepared at 9 atm showed consistency of foam and a high content of key odorants resulted in freshness and fruity, malty, and buttery flavours. A simple discriminate analysis helps to classify ECs prepared at various pressures into respective groups with a confirmed success rate of 100%. The influence of water pressure and other factors on the quality of EC were further markedly reported in detail by Andueza *et al.* (2020).

Essential oils and phenolic substances extraction

Phenolic compounds, obtained from plants are important in functional foods, biomaterials-and pharmaceutical industries. On the other hand, many of the traditional current extraction methods, show some disadvantages relatively long processing times, contamination by traces of solvents, and degradation of some components. While shockwave-assisted extraction is fast, efficient, eco-friendly, easy-to-use, reliable, and non-destructive. Kuraya *et al.* (2014a, b) exposed the leaves of *Alpinia zerumbet*, an aromatic plant, to underwater shockwaves as a preprocessing step for steam distillation of the leaves. Shockwaves treatment resulted in multiple cracks, and selective effective destruction of the fiber and/or cell structures, as shown by the scanning electron microscopy. The extracted essential oil has an effective numerous biological functions. The volatile compounds concentration was found to increase with the number of shockwave processing. Examples are the concentrations of the extracted camphor and *p*-cymene which increased more than four times compared with the content of the untreated leaves. The headspace gas chromatography/mass spectrometry indicated that the volatile components within the structures were easily volatilized.

A plant with high concentrations of many essential and functional components is *Eysenhardtiapolystachia* heartwood, a medicinal tree spread across Mexico and Texas. The plant has been used as a diuretic and to treat urinary tract and bladder infections, and also has ant diabetic and antibacterial effects. According to Gustavo *et al*. (2020), extraction of powdered samples revealed that shockwave-assisted extraction produced higher contents than Soxhlet and ultrasound-assisted extraction (USE). Accordingly, shockwave extraction is recommended as an attractive method to obtain both phenolic acids and flavonoids without the need for organic solvents within 5 min, compared to 96 h for solvent extraction by Soxhlet apparatus.

Glass recycling

The shockwave technology has also an indirect effect in the food industry; namely, in food packaging. An example of that is through glass making and recycling. Broken or refuse crushed glass, or cullet is usually added to new material and used throughout glass manufacturing. It is a key to facilitating melting in making glass. A Study about glass bottles recycling using the underwater shockwaves technique was proposed by Kawabe *et al.* (2006). The small fragmentation technique of glass bottles showed many excellent advantages as the simplification of the process by simultaneous cleaning and crushing operation.

Major challenges

The major challenges facing the industrial implementation of underwater shockwave technology include the lack of appropriate packaging materials, which can be resistant to the disruptive effects of shockwaves, the capital required, and a lack of much-required information about USP. So far, most studies of underwater shockwaves on food are at the laboratory scale and validation stage. Further research endeavors and collaboration between food scientists, engineers, and regulators are necessary to scale up this technology to industrial implementation, (Ying *et al.*, 2020). On the other hand, Kemal *et al.* (2021) reported that the total processing costs of that technology are estimated in a range of a few Euros per ton of the treated product. Generally, the application of shockwaves in the food industry is still limited to the present time.

CONCLUSION

According to Josef *et al.* (2020), the shockwave apparatus is a device capable of deep intracellular disintegration with no increase of temperature of the treated commodity, and no need for additional reactants. The best ways to generate these destructive forces are short circuits of high-voltage or wire explosions. The resulting expansion pressure wave spreads through the liquid environment to the exposed product, breaking the walls and some internal parts of the cells. Current development focuses on multiplying pressure waves inside the chamber, reduction of dimensions, and performance to increase a continuous processing condition. The technology is recommended as a commercial promising process for the production of essential oils and other highly prized commodities. However, energy requirements are still high. There is a wide consensus that shockwaves may become tomorrow’s novel continuous processing technology for producing novel and great-tasting foods and other products with maintaining many of the natural quality characteristics of the product.

Mohammad *et al.* (2021) studies provide fundamental stone into the world of shockwave emissions, which can be effectively used to develop, validate and optimize various industrial processes. That should be further studied as a subject of future upcoming investigations.

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الموجات الصادمة تكنولوجيا واعدة لتحسين جودة الأغذية المصنعة: نظرة شاملة

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تعرف تكنولوجيا الموجات المائية الصادمة بأنها عملية تتم بنظم توليد ضغط ميكانيكي قوي تحت الماء بدأً من الجيل الأول لتلك في التسعينيات باستخدام الانفجار explosive، أما الجيل الثاني فكان بالموجات الكهربية electrical current أي ضغط قوي تحت الماء يسري ليصل إلى المادة المزمع معاملتهاز تساعد تلك التكنولوجيا على تفكك الأنسجة الحيوية، تساعد على استخلاص المكونات الحيوية النشطة، تسهل من عملية التجفيف، تحسن من تركيب الغلال لزيادة عائد الطحن، تساعد في تأخير تلف بعض الأغذية مع استخدام بعض عوامل الإعاقة الأخرى hurdles. أهم التطبيقات التي يتم العمل على تحسينها هي نظرية اللحوم، كذا تأخير تلف بعض قطعيات اللحوم الطازجة المبردة. كما تجد تطبيقات تلك التكنولوجيا المستحدثة طريقها في القضاء على الميكروبات المسببة للتلف والميكروبات الممرضة.

تجد تلك التكنولوجيا طريقها لى النطاق التجريبي، كما جاء في التغطية التاريخية الموجزة التي تم تناولها في النظرة الشاملة الحالية، ذلك كنواة لتطبيق تلك التكنولوجيا على النطاق الصناعي بعد التغلب على بعض المعوقات التي تم الإشارة إليها والتي تحد من تطبيقها.