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Review Paper

Potential of Non-Thermal Processing for Food Preservation in Southeast Asian Countries

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Abstract: The application of non-thermal processing technology (NTP) is increasing within the food industry. The absence of heat in this technology offer some advantages such as the sensory and nutritional attributes of the product remaining unaffected, thus yielding products with better quality compared to traditional processing methods. Suitability of technology for a certain application varies according to the nature of the reason and the purpose for processing. Some NTP has long been used in the food industry in Southeast Asia, but most are still at the initial stage of research. Despite several existing challenges, these technologies have the potential to be taken up as an alternative to processing of value-added food products especially now when consumer and trade demands as well as economic strength in the region is changing.

Keywords: Nonthermal processes, food preservation, microbial inactivation, food quality

INTRODUCTION

Non-thermal technologies (NTP) are processing methods for achieving microbial inactivation without exposing foods to adverse effects of heat whilst extending product shelf life and retaining their fresh-like physical, nutritional, and sensory qualities (Ade-Omowaye *et al.*, 2001; Butz and Tauscher, 2002). These technologies include pulsed or radio frequency electric fields (PEF/RFEF), ultraviolet light (UV), ultrasound (US), pulsed light (PL), high pressure processing (HP), ionizing radiation, dense phase carbon dioxide ($DPCO_2$) and ozone. The most extensively researched and promising non-thermal processes appear to be high hydrostatic pressure (HHP), pulsed electric fields (PEF) and high-intensity ultrasound combined with pressure. Gamma irradiation has long been developed and researched and it has high potential in producing safe and nutritious food. Unfortunately, its development and commercialization has been hampered in the past by unfavourable public perceptions (Resurreccion *et al.*, 1995). Electron beam on the other hand is more likely to succeed than gamma rays in the long run as there is no limitation in supply of raw materials such as cobalt-60. It is more expensive in terms of initial costs, but its consistent performance outshines gamma irradiation.

Interest in NTP technologies have been increasing among food researchers and manufacturers, mainly due to safety concerns about the generation of carcinogens or harmful materials such as acrylamide found in baked and fried foods or other thermally

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processed products. Efforts have been made to improve non-thermal devices (Forney and Pierson, 2004) with efficient microbial inactivation capabilities, without generating harmful compounds. Technologies which were designed for non-food purposes have now been modified for food applications and positive progress have been reported. Recently, a booming market for nutraceuticals and functional beverages in Asia as well as price cuts for vitamins, minerals and pharmaceutical products in China has led to the increased trends in food fortification (Frost and Sullivan, 2006). This is an opportunity for those who would like to take advantage of NTP technologies to ensure safety and quality of food products. The timing is perfect with the rise in health awareness among consumers. Like any other process, NTP can be combined with thermal or other processes as a hurdle technology or as a compliment to other processes. Combining non-thermal processes with conventional preservation methods enhances their antimicrobial effect so that lower process intensities can be used (Ross *et al.*, 2003). Regardless of the approach, mechanisms and specific targets, these technologies are tools for manufacturers to achieve the same objectives of quality and safety of manufactured food products. It is the purpose of this article to address the opportunities for NTP processing in the Southeast Asian region and to describe some of the applications currently researched and potential applications to be used within the food industry.

Application of Non-thermal Technologies in Food Processing

Non-thermal processing (NTP) treatments are gentler than thermal treatments, with targeted function for certain microbial inactivation and quality of products. The ability to retain flavor and aroma after NTP application is a huge advantage for Asian foods which often have stronger taste and aroma compared to Western foods. The vast variety of flavorful food in Southeast Asia such as fruits and fruit juices, sauces and seasonings, cereals, grains, flour and starches, seafood and meat products, snacks, and traditionally preserved foods (fermented, salted, added sugar) creates potential for the commercial application of NTP technologies. Some of these technologies are suitable for small scale entrepreneurs and some are suitable for large businesses. Besides cost, suitability of the technology and the targeted objective of processing the product must also be evaluated.

a) Ultraviolet Irradiation (UV)

Ultraviolet radiation has been used for several years as a physical disinfection medium for air, surfaces and liquids. During processing and storage of liquid foods, contamination can take place in many different contact points (incoming raw materials, storage vessels, air in storage vessels, equipments, rinse water, drinking water and water to be added to foods). UV irradiation can and has been used at these contact points to reduce microbial load and minimize contamination (Ngadi *et al.*, 2004). UV light (254 nm) can be used to inactivate many types of organisms, including viruses and has been used for many years in pharmaceutical, electronic, and aquaculture industries as a disinfection medium. Microorganisms exposed to UV light are affected at the DNA (deoxyribonucleic acid) level. Thus, the injured reproduction systems of cells lead to their death. Exposure to UV light can be applied at different doses for pasteurization of liquid foods or disinfection of solid foods (Guerrero-Beltr·n and Barbosa-C·novas, 2004). Fresh fruit and vegetable products in pumpable form can be processed using UV light to reduce food-borne microbial load. Most of these products are commonly pasteurized but unfortunately, heat from thermal pasteurisation can negatively change the taste and flavor of such products. However, when using very high UV doses for food disinfection, loss of nutritional value and undesirable appearance, may take place (Mohd Adzahan, 2006; Gardner and Shama, 2000). FDA has approved UV irradiation (21

CFR 179.39) for use on fruit and vegetable juices and juice products to achieve the 5-log reduction of target microorganisms such as *E.coli* O157:H7 or *Cryptosporidium parvum* as part of HACCP rule compliance (CFR, 2000). Processors also may use chemical antimicrobial agents, such as certain sanitizers, on the surface of citrus fruit as long as FDA has approved the chemical agent. It has a relatively lower initial investment compared to heat pasteurization and the equipment is easy to operate (Worobo *et al.*, 1998; Choi and Nielsen, 2004). In addition, UV pasteurizers do not take up a lot of floor space and losses of ascorbic acid, thiamine, riboflavin, pyridoxine and nicotinic acid due to UV exposure at 14 mJ/cm^2 are comparable to those in heat treated juices (Mohd Adzahan, 2006). In the cases of quality and consumer acceptability tests, there seemed to be little difference between cider samples that were untreated and those that were UV-pasteurized (Choi and Nielsen, 2004; Tandon *et al.*, 2003), which is an indication of the fresh-like product quality. Researchers in New Zealand studied UV treatment of orange and carrot juices (Tran and Farid, 2004), while European researchers are fast catching up. Until 2006, there was no report in Southeast Asia on UV related research or application for food processing. Tropical juices are most often sweet and less acidic compared to cider, hence the crucial microbial reduction step to preserve the juice and ensure safety of the product. Guava, papaya, and pineapple juices are high in ascorbic acid and exposure to heat treatment will diminish their nutritional value. These juices may be suitable for UV processing as long as they do not have high initial microbial populations, particulate materials and organic compounds. Such properties will prevent low transmissivity of UV light (Guerrero-Beltran and Barbosa-C·novas, 2004) and hamper consistent exposure of UV energy throughout the juice. Processing helps to reduce initial counts of yeast and mold in the juice or filtering the juice through membrane technologies before UV irradiation will result in higher efficiency for microbial inactivation by UV light (254 nm). Clear and less turbid juices such as coconut water, sugarcane and chrysanthemum juice all have the potential for UV application as a more economical alternative to heat pasteurization. Rice and soy milk are also potential products for UV treatment but no data has been published on UV treatment of these drinks. A greater than 5-log reduction of *Listeria monocytogenes* was achieved when goat milk is exposed to a cumulative UV dose of 15.8 ± 1.6 mJ/cm^2 (Matak *et al.*, 2005).

Shelf life of UV treated mango nectar lasted for 20 days with almost no microbial growth. The nectar maintained yellow and orange-yellow colors, after 26 days of storage and polyphenoloxidase activity remained constant after 30 days. However, the lower the flow rate during UV treatment, the higher the browning of nectar during storage. The maximum log reduction (CFU/mL) in UV treated (30 min of UV exposure at 0.451 liter/min) mango nectar was 2.71 and 2.94 for total microbial count and yeast count, respectively (Guerreo-Beltr·n and Barbosa-C·novas, 2006). There is still a lot of room for research and improvement in this area and it is crucial that studies are conducted on variables such as flow rate, exposure time, type of fruit product, color of fluid and composition of the beverage in order to ensure reduced microbial load, increased shelf life and nutritious with acceptable taste.

b) Ionizing Radiation

New regulations by USDA-APHIS allow countries such as Chile, Brazil Philippines, Malaysia and Thailand to export fruits and vegetables to the United States which increases the capability of these countries in food irradiation (CFR, 2001). Gamma and electron beam irradiation are used to inhibit the sprouting of vegetables, extension of shelf life of fresh produce, control of pathogenic organisms, insect and microbial disinfestations and sterilization of food and food packaging materials (Kanatt *et al.*, 2005; Chouliara *et al.*, 2006; Javanmard *et al.*, 2006). Irradiation of food up to an overall dose of 10 kGy is accepted in several countries for commercial food processing (Lacroix and Quattara, 2000). However, the formation of metmyoglobin when meat was exposed to higher dose was reported (Brewer, 2004). Sausages made from fermented, uncooked pork wrapped in a banana leaf (Nham) are considered a great delicacy in Thailand which has frequently caused intestinal illness due to bacterial contamination. Fortunately, this is no longer the case as irradiation has provided an efficient way of making Nham safe for Thai consumers. Som tam is a popular spicy papaya salad originating from Laos and the Isan region of northeastern Thailand. The main ingredients are fermented fish and salted crab. The ingredients are now irradiated for export. Onions are a highly marketed produce in Thailand, and because of the climate, shelf-life is fairly limited during storage in markets and households. An alternative to systemic chemical treatment (e.g. maleic hydrazide) for sprouting inhibition is the application of absorbed doses of ionizing radiation of about 1 kGy (Biramontri *et al.*, 1989). Effect of gamma irradiation combined with hot water dip and transportation from Thailand to Canada improved the shelfe-life, biochemical and physical characteristics of Thai mangoes (Nahng Glahng Wahn variety) (Gagnon *et al.*, 1993). Reibroy *et al.* (2007) studied the effect of irradiation on properties and storage stability of Som-fug produced from bigeye snapper. It was found that the irradiation at low dose (2 kGy) could be used to control the over fermentation of Som-fug up to 20 days at 4°C without adverse effects on quality and acceptability.

c) Pulsed Light Processing

The FDA has approved pulsed light for the treatment of food (CFR Title 21, Sec. 179.41) for surface microorganism control, with the total cumulative treatment not exceeding 12.0 (J/cm^2) and the pulse duration is no longer than 2 milliseconds (CFR, 2000). The application is suitable for surface treatment of food packaging materials, egg shells, processing equipments and production lines, sliced meats and raw or fresh cut fruits and vegetables (Szabo *et al.*, 2006). Fishermen producing salted seafood products can use this technology to prevent growth of resistant microorganisms; especially so that the intensity of pulsed light is more than the sunlight. The germicidal effect appears to be due to both the high UV content and the brief heating effects which come from the infrared portion of the light. While UV causes damage to the nucleic acid and other components of the cell, the instantaneous heating of the cell results in the rupture of the cell wall, or lysing (Wekhof, 2000).

d) Pulsed Electric Field (PEF)

PEF is the application of short-duration pulses (1-100ms) of field strength (10-50 kV cm^{-1}) to a product placed between two electrodes. Recently, the continuous flow-through chambers has developed and upgrading offer possibilities (Qin *et al.*, 1998). Microbial inactivation by PEF is believed to be caused by the PEF on the cell envelopes. PEF can cause formation of pores affecting the integrity and functionality of the membrane. These pores can be reversible or irreversible, depending on the degree of membrane damage (Ho and Mittal, 1996; Weaver and Chizmadzhev, 1996). Under mild pulsation conditions, the pore formation in the membrane will be reversible, whereas more drastic conditions will lead to irreversibility of this phenomenon, which will eventually result in cell death (Barbosa-C·novas *et al.*, 1999). The optimum conditions of inactivation of microorganisms depend on species and processing conditions (Abram *et al.*, 2003; Rodriguez-Calleja *et al.*, 2006). The main parameters are electric field strength, pulsed length, number of pulses, pulse shape and starting temperature (Wouters *et al.* 2001). Physical and chemical characteristics such as pH, conductivity and ionic strength of the medium in which the microorganisms are PEF treated can influence microbial inactivation

(Alvarez *et al.* 2000). Sub-lethal injury caused by PEF in *Escherichia coli* (Garcia *et al.*, 2003) and the effectiveness of PEF to inactivate enzymes has been reported (Giner-Segui *et al.*, 2006).

e) High Pressure Processing (HP)

Sauces and seasonings play a significant role in Asian dishes. Most of these products have been either fermented, salted, dried or added sugar or acid for preservation purposes. Despite that, due to microbial resistance to traditionally harsh conditions, further preservation is needed. A method which is suitable for reducing microbial counts in sauces and seasonings is high pressure processing (HP). Research on HP applications have been done on juices, seafood, pork, milk, fruit jams and eggs (Berlin *et al.*, 1999; Linton *et al.*, 1999; Patterson and Kilpatrick., 1998; PrÈstamo *et al.*, 1999; Mussa *et al.*, 1999; Yuste *et al.*, 1999; Ponce *et al.*, 1999). Surimi gels from Pacific whiting obtained by HP were less opaque than traditionally heat set gels and had higher stress and strain values than those of heat set gels (Chung *et al.*, 1994). Guacamole, a product made from avocado has high fat content and very low acid and has been processed using HP and commercialized (San Martin *et al.*, 2002). The durian fruit has high fat content and low acid just like guacamole. 'Tempoyak', a fermented Malay side dish made from this fruit may be suitable for commercialization using HP processing. Durian has a variety of volatile flavor compounds or/and aroma and its texture, taste and smell can be altered by heat (Voon *et al.*, 2006), which is the reason why NTP should be seriously considered as an alternative to a thermal process.

Nuts have the potential of causing harmful diseases such as salmonellosis as well as intoxication from aflatoxins. Reports on raw almonds treated with high hydrostatic pressure to reduce *Salmonella enteriditis* have proven effective and the same application can be used on peanuts and other nuts, soybeans and legumes. This is done by suspending the food to be pressurized directly in the pressurizing medium (water) which would increase the A_w of the food, leading to an improved reduction in the concentration of vegetative bacteria (Goodridge *et al.*, 2006).

A type of soybean vegetable protein that Asians have long consumed and its intake is increasing in other countries is known as tofu. High pressure treatment of tofu at 400 MPa at 5°C for 5, 30, and 45 min showed reduction of the Gram-negative and Gram-positive microorganisms without causing any negative effects in terms of its sensory properties. Micrographs on the cryofracture observed with a cryoscanning electron microscope revealed a more compact structure after pressure compared with that of untreated samples, but the aggregates in the treated samples were more disperse (PrÈstamo *et al.*, 2000). One study reported that soybean-to-water ratio of 1:8 ratio at pH 7 led to pressurized soymilks which have color and viscosity properties similar to the untreated soymilk, with enhanced emulsion stability (Lakshmanan *et al.*, 2006).

f) Dense Phase Carbon Dioxide (DP-CO_2)

DP-CO_2 or supercritical and liquid CO_2 is a cold pasteurization method that affects microorganisms and enzymes through molecular effects of CO_2 under pressure and suitable for juices and dairy based beverages. Pozo-Insfran *et al.* (2006) reported that thermal pasteurization decreased anthocyanins (16%), soluble phenolics (26%), and antioxidant capacity (10%) whereas no changes were observed for DP-CO_2 Muscadine grape juices including its sensory attributes. Application of DP-CO_2 extraction includes extraction of lycopenes from tomatoes, removal of caffeine from tea or coffee, extraction of flavor and aroma from hops in breweries, freeze-drying of vegetables and removing fat from animal products such as powdered eggs. The pharmaceutical industry also uses DP-CO_2 extraction to remove medicinal compounds from herbs.

g) Ultrasound and °zone

Ultrasound is energy in the form of sound waves with a frequency greater than 20 kHz. It has proven bactericidal effects, especially when combined with other microbial-reduction strategies such as mild heating or pressure. A combination of pressure, thermal and ultrasound is called manothermo-sonification (MTS) and this combination has been proven to be more effective in reducing pathogenic microorganisms and in retaining quality of juices (Kuldiloke, 2002). Ultrasound treatment (sonifier probe at 20 kHz, 100% power level, 150 W acoustic power, 118 W/cm^2 acoustic intensity) combined with mild heat (57°C) for 18 min resulted in a 5-log reduction of *L. monocytogenes* in ultrahigh-temperature milk, a 5-log reduction in total aerobic bacteria in raw milk, and a 6-log reduction in *E. coli* O157:H7 in pasteurized cider (D'Amico *et al.*, 2005). Ultrasound is now applied to food products for microbial an enzyme inactivation and for food extraction via mechanical actions. Ultrasonic cavitation produces shear forces which breaks cells mechanically and allows material transfer from cell into solvents. Particle size reduction by the cavitation increases the surface area in contact between liquid and solid phases, an advantage when extraction of compounds is expected. The technology has been used for extraction of phenolic compounds from vacuolar structures by disrupting plant tissues, extraction of lipids and proteins from seeds, emulsification, viscosity improvement, homogenization and improvement of dispersion stability in liquid foods. This technology has also been used for salads, vegetables, fresh poultry, sauces, confectionaries, beverages, juices and purees, dairy products, as well as for sanitized washing and for waste water treatment. For poultry products, ozone in combination with ultrasound is an option to reduce microbial counts. Ozone can be used for both the products and also the equipment and facility, doesn't leave a residue, eliminates the storage problems associated with peroxide, chlorine dioxide and other sanitizers and is more effective in reducing pathogen loads (Ngadi *et al.*, 2004).

Regional Issues

a) Post-Harvest Losses and Aquaculture

Southeast Asia is endowed with agricultural resources and seafood products but in terms of trade, disruptions due to shortcomings in food quality have also been on the increase. Many local fruits with the potential for commercialization are grown sporadically in small farms. These fruits are often seasonal with many healing and anti-oxidative properties, but are highly perishable. Pre and post harvest losses in Asian countries range from 20-50% (Senik, 1995; ASEAN, 2006). The region's climate adds more stress and accelerates the decay of tropical produce through increased respiration rate. To overcome unnecessary losses, ASEAN has conducted the project on Quality Assurance Systems for ASEAN Fruits (QASAF). These systems cover post-harvest handling techniques and minimal processing for selected fruit types. Unacceptable pesticide residue levels in fruits and vegetables, antibiotic residues in seafood and poultry mycotoxins in crops and peanuts produced within the region have been the cause of rejection of food export from the Asian region since 2001 which contributed to a huge trade loss (de Haen, 2002). Such unnecessary losses can be prevented using cost effective methods or technologies to preserve the shelf life and quality of raw materials and processed foods. This is a step which can be accomplished using selected non-thermal processing technologies depending on the purpose of treatment and nature of the food.

Aquaculture or fish farming has expanded dramatically in the past few years. The consumption of aquatic plants and raw or partially cooked freshwater fish has been associated with food borne trematode (FBT) infections, which has been a major problem in East and Southeast Asia causing trade loss and health issues. The economic impact of

FBTs was estimated in Thailand to be US$ 65 million (lost income per annum), with additional US$19.4 million for treating infected individuals. Another example is a ban on fish imports into the EU which cost one Asian country $335 million of lost export opportunities (de Haen, 2002). A more secured food chain can be established if such raw aquatic products could be treated before reaching consumers to prevent diseases caused by parasites and microorganisms. Food safety measures and good handling practices and microbial reduction treatments such as NTP technologies (UV, ozone) to treat the ponds and facilities can eliminate the risk of FBTs. However, these safety measures can be very difficult to implement in small-scale subsistence aquaculture situations.

b) Microbial Resistance to Harsh Environments

Microorganisms can adapt to survive severe environments which were traditionally harmful to them. This is especially true of bacteria that have modified their DNA by chromosomal mutation and by acquiring resistance genes via conjugation, transformation, and even transduction. There are seemingly no boundaries to the capabilities of some microorganisms to develop resistance (Wood and Moellering, 2003). Products which have been preserved using acid, salt and sugar may no longer be well preserved due to microorganisms becoming resistant and consequently survive harsh environments.

Apple cider, an acidic product is traditionally safe for consumption and consumed raw. Cider producers are reluctant to use heat pasteurization mainly due to the cost and its destructive effects on the flavor and aroma of ciders. They are often small scale businesses which have their own niche market, and prefer technologies which do not change the flavor of raw cider. However, due to microbial resistance, many life-threatening outbreaks such as infections from enterohemorrhagic (EHEC) strain designated *E. coli.* O157:H7. *E. coli* have taken place (Leyer *et al.*, 1995; Cheng *et al.*, 2003; CDC, 2006). This is the reason for the extra precaution of treating ciders to ensure their safety. Fortunately, they can now use UV irradiation, an approved method to reduce microbial counts (Worobo *et al.*, 1998) and maintain the taste of raw cider (Tandon *et al.*, 2003; Choi and Nielsen, 2004). Southeast Asia is well known for soy sauce, fish sauce, fruits in syrup pickles, dried and salted seafood or meat products. Some of these products are produced in the backyard industry and changes in microbial resistance can take place without the producers realizing as there were no quality control procedure in some facilities. This is an important aspect of processing and preservation because what was confirmed to work last time may not be effective anymore.

Challenges for ASEAN Countries

a) Cost

Cost-effectiveness is a major concern that needs to be addressed besides proper selection of a processing method for a product. Some NTP technologies are relatively more costly than others (Majchrowicz, 1999). If the overall cost and efficiency can be justified with consumers' perceived product quality improvement, then food manufacturers and investors will consider investing in such technologies. Since heat production during NTP is not substantial, a cooling step is not necessary after treatment. This makes the process relatively economical compared to thermal pasteurization. For example, the cost of pasteurization (~ 5 US cents/gal) is feasible for most medium to large-size juice plants with a sound investment of product safety (Kozempel *et al.*, 1998). However, for small scale juice producers, they could produce a quality product without residual chemicals or radioactivity (Morgan, 1989) and with high retention of volatile flavour compounds at a lower cost (~ 2 US cents/gal) through the use of UV irradiation (Higgins, 2001). Since UV pasteurizers cost around $15,000, this allows cider producers, who have very little capital investment abilities, to utilize a cheaper processing method than thermal pasteurization, which costs $20,000–$30,000 (Majchrowicz, 1999). In short, its effectiveness in reducing food borne pathogens with minimal installation, employee training and licensing costs may allow the commercialization of UV treatment for small-scale operations.

b) Consumers Rule

Some NTP technologies like irradiation, electric fields, ultrasound and ultraviolet light are often not well perceived, leading to misunderstanding and rejection by consumers of treated food products. They relate these technologies to harmful events, toxicity and most likely will assume higher pricing for products treated with such technologies. Proper consumer education to increase awareness on applications of NTP technologies are important and must be carried out to promote consumer acceptance and further diversify options for food processing manufacturers to produce safe, fresh-like and quality products.

c) Competitive International Trade

ASEAN Economic Community plans to establish ASEAN as a single market and production base, turning the diversity that characterizes the region into opportunities for business complementation and making the ASEAN a more dynamic and stronger segment of the global supply chain which creates economic competitiveness (ASEAN, 2006). This is a challenge for ASEAN countries, but with the establishment of AFTA and other guidelines or trade policies such as Halal food production and certification in the region, this challenge can become a strength. Muslims make up half the population of Southeast Asia today with Indonesia having the world's biggest Muslim population (CIA, 2006). Therefore, Halal certification is not just a concern in Islam as a religion but also a concern in business as it is a mark for product safety and quality as well as money-spinning business due to high consumer demands.

Final Remarks

Non-thermal processing technologies have the potential to improve food chain security and add value to food products. Southeast Asia has the strengths, capacity and reasons to support the use of NTP. Economic limitations suggest that suitability and hurdle technology studies are crucial in order to get NTP technologies to move closer to the realm of commercialization in Southeast Asia.

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