Emerging Technologies in Food Processing

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INTRODUCTION

“The heat is off” was the headline on the cover of an international magazine in 1993 (Anon, 1993) demonstrating the shift of consumers, researchers and the food industry to non-thermal processing as a reaction to conventional thermal processing and subsequent quality losses of foods. Although, there are clear benefits attributed to thermal processing (van Boekel et al., 2010), overprocessing was and is frequently applied to ensure necessary and expected food safety requirements. Thus, with the development of gentle (“schonende” as a better German term), “non-chemical”, low energy and sustainable technologies based consumer demands of the 1990’ies and thereafter, the safety margins of traditional thermal processing had to become narrower requiring a thorough understanding of the technology used, better process controls and sensor/indicator development for monitoring key processing parameters.

Further, process responses of microorganisms, toxins, contaminants, food materials, as well as impacts on food safety, quality and functionality needed to be evaluated and kinetic and mechanistic data be accumulated.

This requirement for a science-oriented process development, in contrast to the conventionally empirical one, became and still is the key challenge for a sophisticated process and product development for targeted food process delving desirable food properties.

The concept of Process-Structure-Property relationships was developed in the vision document Strategic Research Agenda of the European Technology Platform: Food for Life (SRA, 2007) where the “Reverse Engineering” concept was also formulated, requiring future food processing technologies to be adapted to the preferences-acceptance and needs requirements of the consumers (Figure 1 and Figure 2).

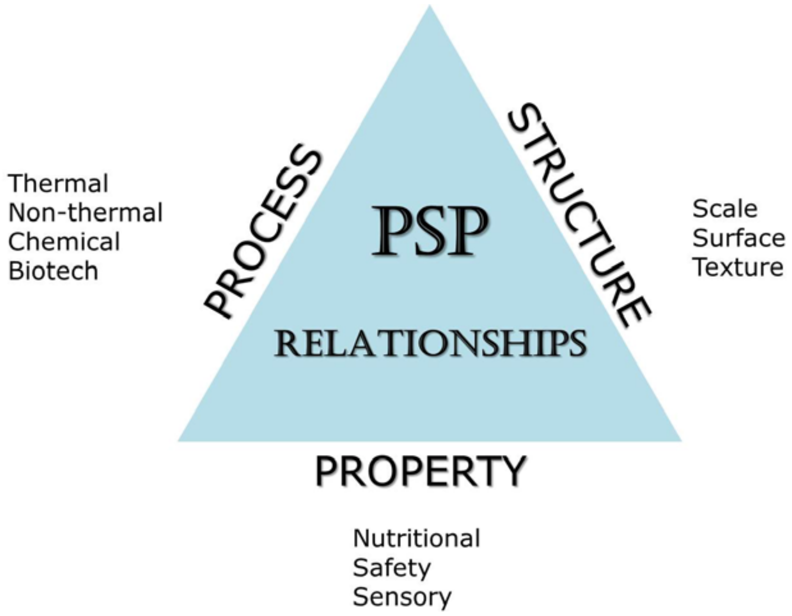


Fig 1: Process-structure-property-relationship for food processing

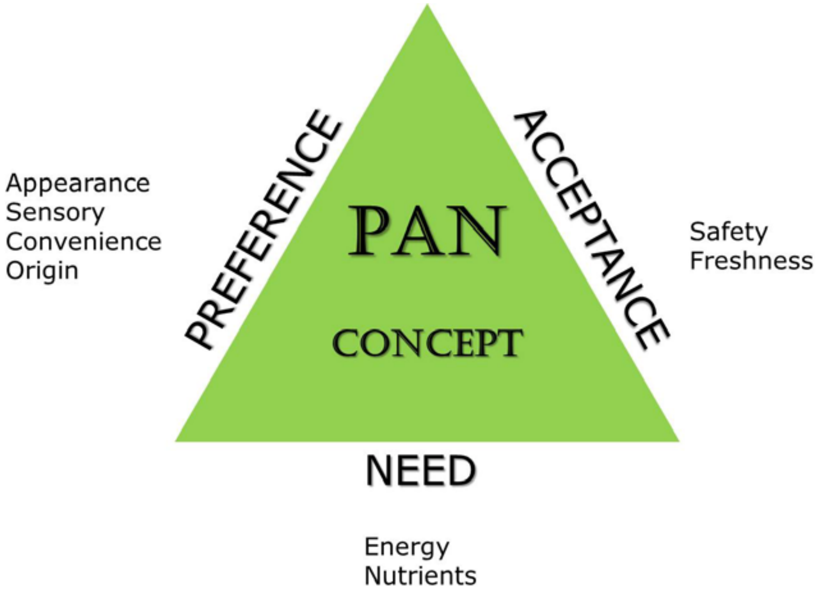
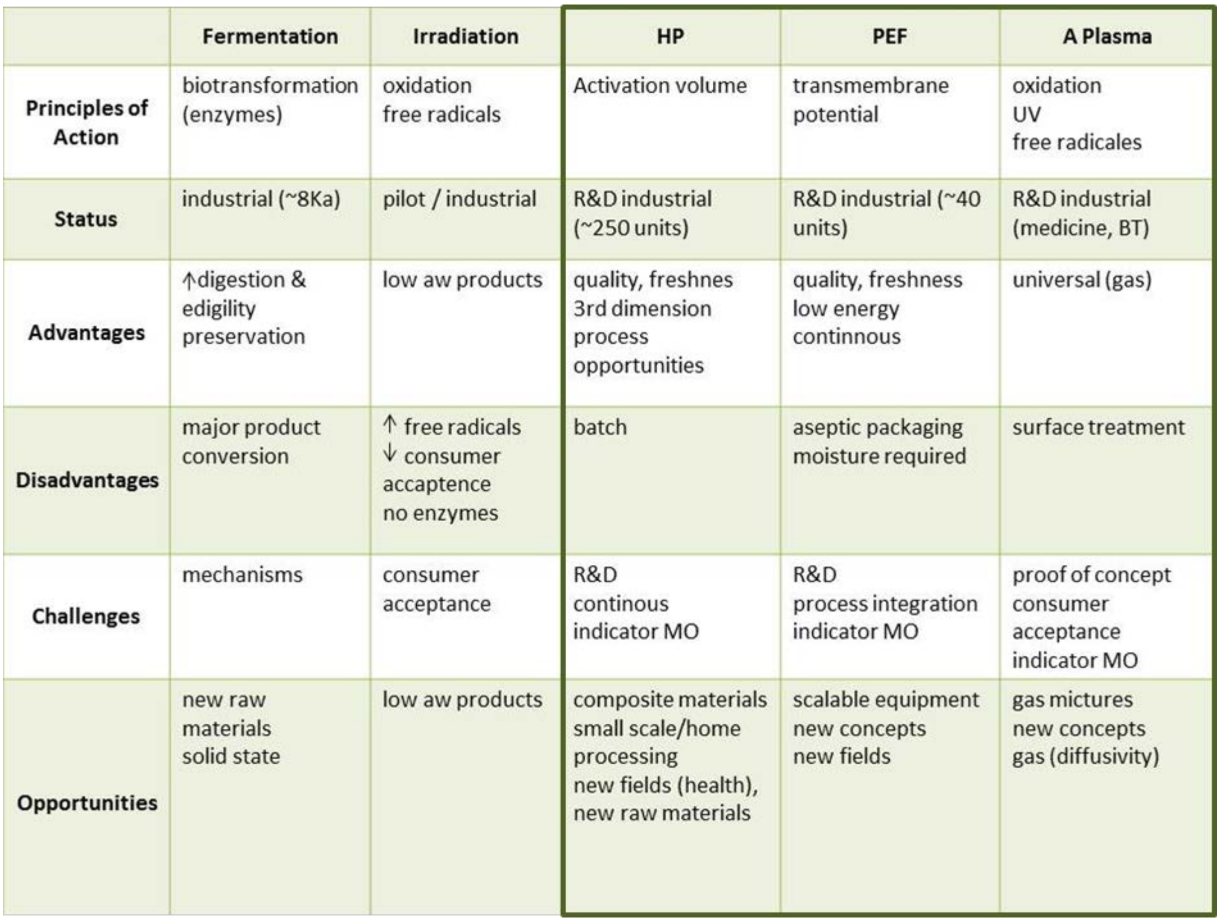


Fig 2: Preference-acceptance-needs requirement of consumers concept

The Senate Committee SKLM of the DFG, in response to the challenges discussed above has provided opinion documents regarding food safety assessments on key emerging technologies including high hydrostatic pressure (Eisenbrand, 2005), pulsed electric field (Knorr et al., 2008), atmospheric pressure plasma (Schlüter et al., 2013) and ohmic heating (Jäger et al. 2016).

This paper will briefly discuss knowledge gaps and research needs of three technologies and attempt to give an outlook on their future roles in food research and development (Figure 3).



	Fermentation	Irradiation	HP	PEF	A Plasma
Principles of Action	biotransformation (enzymes)	oxidation free radicals	Activation volume	transmembrane potential	oxidation UV free radicales
Status	industrial (~8Ka)	pilot / industrial	R&D industrial (~250 units)	R&D industrial (~40 units)	R&D industrial (medicine, BT)
Advantages	↑digestion & edigility preservation	low aw products	quality, freshnes 3rd dimension process opportunities	quality, freshness low energy continnous	universal (gas)
Disadvantages	major product conversion	↑ free radicals ↓ consumer accaptence no enzymes	batch	aseptic packaging moisture required	surface treatment
Challenges	mechanisms	consumer acceptance	R&D continous indicator MO	R&D process integration indicator MO	proof of concept consumer acceptance indicator MO
Opportunities	new raw materials solid state	low aw products	composite materials small scale/home processing new fields (health), new raw materials	scalable equipment new concepts new fields	gas mictures new concepts gas (diffusivity)

Fig. 3: Comparison of key non-thermal technologies. HP (high pressure), PEF (pulsed electric fields) and A Plasma (atmospheric pressure plasma).

PRINCIPLES OF EMERGING TECHNOLOGIES

High hydrostatic pressure

High hydrostatic pressure is based on activation volume, uses a transferring medium and is currently only applied in batch processing units. The Le Chatelier’s principle indicates that an application of pressure shifts the equilibrium of a system to the state that occupies the smallest volume. Therefore chemical or physical changes (phase transitions, chemical reactions and molecular configuration changes) that result in a volume decrease are enhanced by the application of pressure. Consequently non-covalent bonds are affected while key food quality parameters remain mostly unchanged. However, enzyme reactions can occur (e.g. during pressure build up phase before inactivation), adiabatic heating takes place (approx. 1-2°C per 100 MPa) and temperature and pressure distribution in processing units is not entirely homogenous. Currently there exist almost 300 industrial scale units worldwide (Perez, 2015) most of them exclusively devoted to pasteurisation (inactivation of vegetative microorganisms).

High pressure processes

High pressure is applied at low, ambient and high temperatures enabling rather unique process and product opportunities (Schlüter et al., 1998; Hendrickx and Knorr, 2002; Bauer and Knorr, 2005; Luscher et al., 2005; Volkert et al., 2008; Tintchev et al., 2013; Sevenich et al., 2014).

High pressure low temperature

Bridgman (1912), the Novel Prize winning pioneer of high pressure research showed the first phase diagram of water under pressure and demonstrated a freezing point depression to -20°C at 200 MPa. This offers a vast potential of applications for food science, medicine and biotechnology (Urrutia Benet et al., 2004). Recent data also indicated the changes of protein functionality when subjected to phase transitions (Baier et al., 2015a).

High pressure ambient temperature

Substantial progress has been achieved since the early reviews on effects on microorganisms (Chlopin and Tammann, 1903; Hoover et al., 1989; Hendrickx and Knorr, 2002; Rastogi et al., 2007; Barba et al., 2015). In addition, the impact of high pressure on shigatoxin producing *E.coli* 0104:H4 and 0157:H7, organisms responsible for an outbreak in in Germany 2011, has been evaluated (Reineke et al., 2015b), as well as its effect on mealworm larvae (*Tenebrio molitor*) decontamination demonstrated (Rumpold et al., 2014). Meinlschmidt et al. (2015) provided an innovative approach to reduce key soy protein allergens by a combined high pressure proteolytic enzyme treatment process.

High pressure high temperature

Impressive groundwork regarding the inactivation of bacterial spores (Sale et al., 1970; Gould, 1977) has been provided. More recently, this has been re-initiated by Heinz (Heinz, 1997; Heinz and Knorr, 1998) followed by subsequent work on kinetic modelling and mechanistic insights (Georget et al., 2014; Georget et al., 2015; Lenz et al., 2015; Sevenich et al., 2015) including a convincing demonstration of a possible spore inactivation mechanism via denaturation of spore DPA-channels, proteins (Setlow, 2003; Reineke et al., 2013). Sevenich (2013; 2014) showed the effects on thermally including food contaminants (Furan, MCPD-esters) in real food systems (baby foods, fishes in oil) achieving reductions of almost 90% as compared to conventional thermal retorting. Work on vegetable puree (Palmers et al., 2014) showed similar results.

Pulsed electric fields

Pulsed electric field application is applied to induce non-thermal permeabilization of biological cell membranes. Depending on energy input (external electric field strength, number and duration of electric pulses) and cell properties (size, geometry, orientation in field, electric conductivity), pore formation may be permanent or temporary including stress induction. 100 ms at 0.1-1 KV/km are used for reversible permeabilization and stress induction in plant cells, 0.5-3 KV/cm for irreversible permeabilization of plant and animal tissue and 15-40 KV/cm for irreversible permeabilization of microbial cells (Jaeger et al., 2014). Early examples of pulsed electric field application include Alexander von Humboldt (1807) stunning of horses with electric field pulses emitted by electric cells. Doevenspeck (1960) initiated research leading to commercial food application on fish systems. This work followed by Flaumenbaum (1968), Angersbach (1997), Bazahl and Vorobiev (2000), Raso et al. (2000), Martin (1973) and others (Raso and Heinz, 2006).

Pulsed electric fields at low temperatures

Wiktor et al. (2015) showed on impact of time reduction during immersion freezing and thawing of apple tissues. Baier et al. (2015) could achieve up to 20 % freezing and thawing time reduction for tap water (Richter, 2015).

Pulsed electric fields at ambient temperatures

Grahl (1994) and Wouters (1997) were among the first ones within the European research context working on inactivation of microorganisms followed by Raso (2000) and Toepfl (2003), and Barbosa (1999) in the USA. It is worthwhile to indicate that industrial scale units for pasteurization (Elea, 2016) exist as well as for plant tissue permeabilization (Elea, 2016). Jäger (2006) demonstrated that naturally accruing antimicrobial agents in cow’s milk and mothers milk could be retained after microbial inactivation by pulsed electric fields. In package treatment as proposed by Roodenburg (2010; 2011) would avoid the possibility of microbial recontamination of treated foods during downstream processing (e.g. filling, packaging). Further, reduction of yeast protein RNA could be achieved by pulsed electric field treatment (Moser, 2013) allowing a possible re-introduction of single cell proteins (SCP) as food source. Jäger (2010) showed a reduction of reducing sugars via pulsed electric field induced leaching from potato cells, thus resulting in less acrylamide formation. Balasa (2013) provided data of antimicrobial, antioxidative secondary metabolite production (e.g. polyphenols) from grapes and grape mash after pulsed electric field stress.

Pulsed electric fields at high temperatures

Sterilization of liquid foods by pulsed electric fields was accomplished by Reineke et al. (2015a) opening a new field in pulsed field application. In addition to the above results substantial progress has been made in the medical field (Miklavcic et al., 2012) including industrial applications of the electro-chemo-therapy process.

Consumer acceptance studies indicate the importance of sufficient consumer information's as well as appropriate terminology of novel technologies such as pulsed electric fields (Jaeger et al., 2015).

Cold atmospheric plasma

The "forth state of matter" as plasma is called is quite common in our atmosphere (e.g. Nordic lights), it was first produced by G.C. Lichtenberg (1742-1799) followed by M. Faraday (1791-1967), W. Crookes (1832-1919) and J.T. Thomson (1856-1940) (Surowsky et al., 2013; Surowsky et al., 2014). The German Nobel Prize awardee J. Stark at the University of Greifswald wrote in 1902 the first comprehensive publication about gas discharges in 1902 (Stark, 1902) and initiated the long and successful tradition of plasma research leading to the current Leibniz Institute for Plasma Science and Technology (INP) Greifswald, Germany (INP-Greifswald, 2016).

Plasma is basically ionized gas or gases using plasma jets, dielectric and microwave discharges. Most commonly for food applications nitrogen or argon are used (Surowsky et al., 2013; Surowsky et al., 2014). So far food applications of this surface treatment are mainly at ambient temperatures. Main effects of plasma treatment which has a very low penetration effect in the range of micrometres into food systems are based on UV light and free radical generation. Recent studies on food safety impact of cold plasma include work on spoilage and pathogenic microorganisms in model systems, real foods as well as insects (Rumpold et al., 2014; Surowsky et al., 2014; Baier et al., 2015b)

It is surprising and beneficial that a food quality denaturing enzymes such as polyphenoloxidase and peroxidise have been showed to be also reduced by direct plasma treatment using argon gas with additions of oxygen up to 0.1 % (Surowsky et al., 2013).

KNOWLEDGE GAPS AND RESEARCH NEEDS

The following knowledge gaps and subsequent research needs still exist for emerging technologies in general and also specifically for the three technologies discussed in this paper:

- Limit information exists on the technology impact on nutrients, toxins, allergens and contaminants
- Indicator organisms (such as C*lostridium botulinum* for thermal processing) have not yet been identified
- Kinetic and mechanistic data are still required especially for microorganism and food constituents providing safety hazards
- Different microorganisms respond differently to emerging technologies. Information is required on mechanisms, kinetic data of inactivation and of recovery
- Same enzymes from different plant sources (e.g. PPO, POD…) respond differently (e.g. to high pressure). Mechanisms need to be identified
- Food matrix and composition (e.g. water activity, electrical conductivity) are of major relevance for process responses. Data generation is required
- Process inhomogenities (e.g. temperature, pressure, electric field distribution…) exist. Identification and modelling is needed
- Equipment safety, durability, critical control points etc. need to be established
- Scaleable and robust process and sufficient process control and monitoring (sensor development) are required
- Legal aspects regarding emerging technologies need to be dealt with and necessary data generated

CONCLUDING REMARKS

Emerging technologies are often and in many research projects still being approached as “replacements” of thermal processing technologies. However, in order to use them to their fullest potential, a better understanding of the key principles of the technologies, their principles of action, advantages and disadvantages is required to use them optimally. This will allow entering new fields (e.g. potential for use of new raw materials; radical innovations in process and product design and development, new areas of application outside of food science).

To achieve this science based approach needs to be taken in contrast to the traditional empirical development ones. Further, a real comprehension of the technologies of mechanisms and kinetics, the use of modern toolboxes and working on the interface with other scientific fields is required (Khoo and Knorr, 2014; Knorr and Khoo, 2015).

Finally, integration of the beneficiaries of these emerging technologies – the consumers – is essential and better communication of principles and terminologies of the technologies is needed (Jaeger et al., 2015).

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