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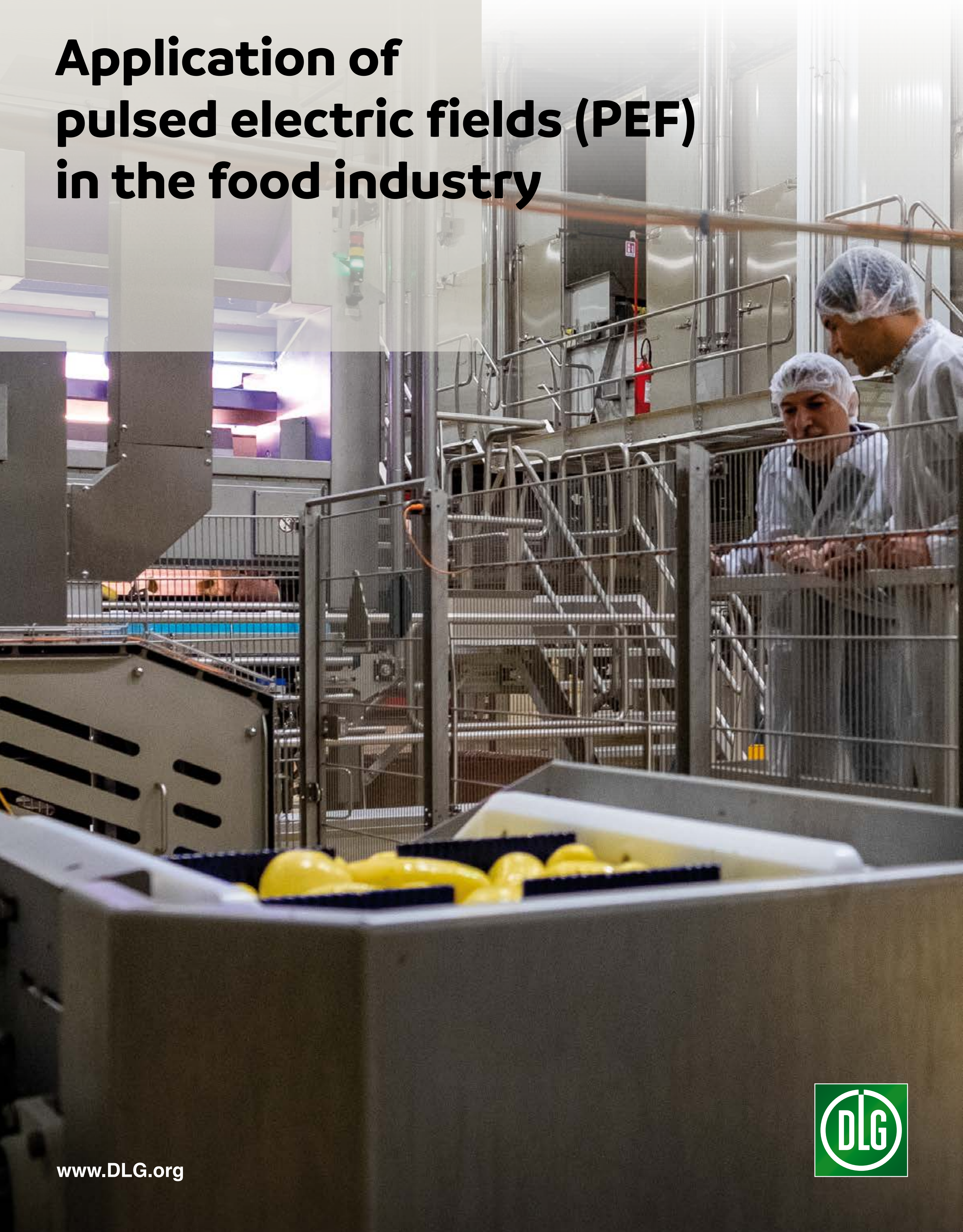

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Application of pulsed electric fields (PEF) in the food industry

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Mechanism of action of PEF

The application of pulsed electric fields (PEF) can be used as an innovative technology in various areas of the food industry and bioprocess engineering. The aim is to influence the cell structure of plants or microorganisms. Although they differ in size and in their composition, all cells are surrounded by a membrane whose main component is phospholipids (Figure 1). Due to the properties of the phospholipids, the membrane can be regarded as an isolator, which is why the cell has a natural charge, the so-called transmembrane potential. Applying an external voltage induces an accumulation of charges and an increase in potential, which causes electro-compression and leads to the formation of pores in the membrane. The process of pore induction by PEF is known as electroporation.

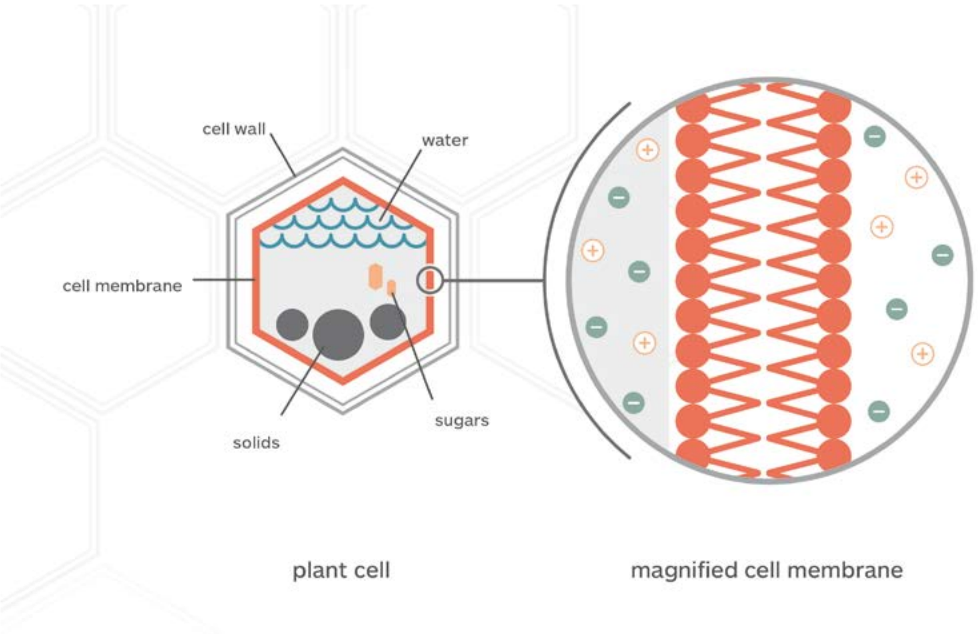

Figure 1: Schematic representation of a plant cell.

Depending on the treatment characteristics (electric field strength, pulse shape and width, energy input), reversible or irreversible pores can be created. Reversible pores are hydrophilic and close automatically after a short time. With higher intensity electrical pulses and prolonged treatment, the initially hydrophilic pores are transformed into hydrophobic pores that cannot be closed again. This causes permanent, irreversible damage to the cell. For the microorganisms present in the product, losing the barrier to the environment means losing viability. Plant cells lose their internal cell pressure through PEF treatment, and the increase in membrane permeability facilitates the transport of substances.

PEF treatment of fruit and vegetables

Potato industry

With the installation of the first industrial plant in the French fries industry in 2010, the use of PEF has successfully established itself in the potato processing industry. Before the introduction of PEF, it was necessary to heat the potatoes at 60°C for 40 minutes in order to soften the potato and prevent undesired enzyme activity. This process is associated with considerable water and energy costs. Compared to a so-called pre-heater, a PEF treatment uses 90% less water and energy. The PEF treatment replaces conventional, energy-intensive pre-heaters and reduces damage during cutting and shortens the process time from around 40 minutes in the pre-heaters to around 10 seconds in a PEF system. By opening the cell membrane and allowing the liquid to escape, the flexibility of the potato is increased, which significantly

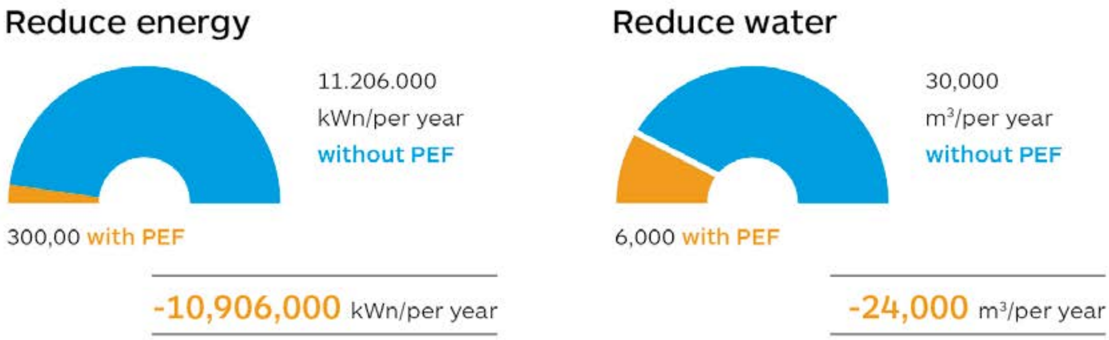

Figure 2: Case study: 26 t/h raw material of a French fries line, 7,700 production hours per year.

reduces breakage during cutting for fries. An improved cut results in a smaller surface area of the fries, which leads to a 10% reduction in fat content. In addition, approx. 10% more starch is retained in the cells. The reduction in starch loss in combination with less breakage results in an increase in yield of 3-4% with the same amount of raw material.

All these improvements enable short amortisation times, making PEF the standard in French fries production. In process lines that operate without a pre-heater, a PEF system pays for itself after approx. 12 to 18 months. If a preheating blancher is replaced by the PEF treatment, the amortisation period is reduced to 6 to 12 months due to the considerable energy and water savings.

The use of PEF has also been very successful in the chips processing industry since 2015. Due to the low moisture content at the end of the frying process, chips are susceptible to the Maillard reaction and the associated brown colouring of the product. By opening the cell membrane, PEF treatment allows reducing sugars to be washed out of the potato more effectively, resulting in a significantly lighter-coloured end product. In addition, the reduced starch loss allows a higher yield as less starch is washed out and improves the crispiness. This leads to improved crispiness and an increase in the yield of the end product. In addition, the improved cut can reduce oil absorption by 10%, which leads to high monetary savings for a product with a fat content of up to 35%. These advantages are not only visible in the production of potato chips but also in vegetable chips, made of sweet potato, carrot and cassava.

Vegetable processing

Eating vegetables is an essential part of a healthy diet. In addition to the large selection of varieties, the diverse preparation options also contribute to consumer demand for a wide range of products. In industrial processing, this is achieved through special production processes in order to be able to offer vegetables in a wide variety of shapes. These include frozen carrots, pickled jalapeños, tinned beans, sweet potato chips and dried tomatoes. The processing steps are very energy-intensive and costly. PEF can make a decisive contribution making the entire value chain more efficient and conserving resources without having a negative impact on the quality.

Cutting is often the first process step in vegetable processing. Depending on the product, this can lead to considerable yield losses. Mushrooms as an example are very sensitive and the stem can easily be cut off. Prior treatment by PEF and the resulting change in product structure makes it easier to cut the mushroom and reduces waste by 10 % (Figure 4). Added to this is the reduced wear on blades seen in the potato industry, which is particularly noticeable with harder products such as beetroot and sweet potatoes.

PEF treatment also offers benefits for peeling raw materials, such as kiwis or tomatoes. The improvement in peelability is due to the migration of water from the pulp under the skin and makes it easier to remove the peel.

Another important process step is blanching. Enzyme inactivation is essential when processing for example carrots as otherwise they will quickly turn brown due to the oxidation reaction. The necessary blanching step can be reduced by up to 50 % with PEF. If blanching is only carried out for the purpose of softening the structure, this step can be completely replaced by using PEF. In addition to softening, PEF treatment also leads to a change in structure. The release of ions activates enzyme reactions that have an effect on the structure and make it harder in some cases. The PEF treatment therefore enables targeted texture management. Depending on the energy input, PEF can therefore also be used to slow down texture degradation during cooking. This effect can also be seen in other types of vegetables, such as broccoli. The use of PEF also benefits the final processing steps. For drying processes, such as hot air, vacuum or microwave drying, increased material and heat transport is beneficial.

After PEF treatment, the cell sap can diffuse to the surface of the product to a greater extent, allowing the water to be removed more quickly and the drying process to be optimised. Optionally, the entire drying process can be shortened, or the temperature lowered in the final drying stage in order to achieve improved product quality (colour, ingredients and shape) and a more energy-efficient process. These benefits apply to a wide variety of products such as onions, apples and carrots. The open cell structure and increased internal diffusion also

Figure 3: Flexibility of untreated (left) and PEF treated (right) green bean.

Figure 4: Difference in yield after cutting of untreated (left) und PEF treated (right) mushrooms.

Figure 5: Comparison of untreated (left) and PEF treated (right) freeze dried strawberry.

optimise product quality in freeze-drying processes (Figure 5). By removing the water more gently, the structure is better preserved, which in turn also facilitates rehydration. When freezing vegetables after treatment, a better distribution of the water on the product surface is achieved and leads to reduced cluster formation.

PEF treatment as a gentle preservation method

Preservation methods are essential to ensure the year-round availability of juices, smoothies and purées as pathogenic, spoilage-causing microorganisms may be present in the product, which can multiply during storage and cause health risks when consumed. In order to inactivate these microorganisms, a preservation step is required, which usually involves thermal processes that have a negative impact on quality. PEF treatment is a gentle method based on the inactivation of microorganisms by electroporation at a lower thermal load. One advantage of PEF treatment over thermal pasteurisation

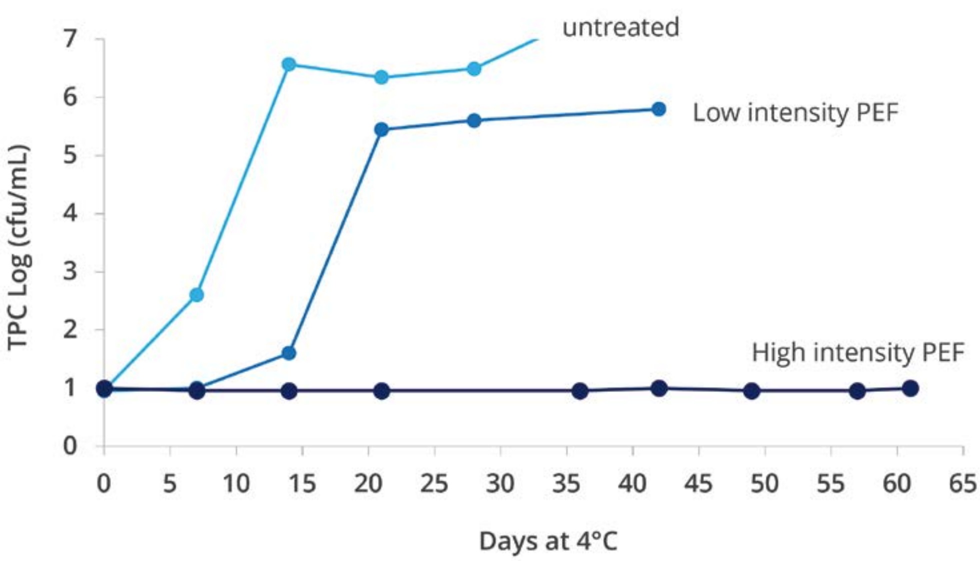

Figure 6: Shelf-life study of fresh orange juice stored at 4°C for 60 days. (TPC – Total Plate Count)

is that it can also be used for heat-sensitive liquids or products with high viscosity. In addition to pasteurisation, spore inactivation is also possible if the PEF treatment is combined with input temperatures around 80°C.

Due to the lower heat exposure during the PEF process, the quality of the product is maintained; changes in colour or ingredients that occur over time are less pronounced than with thermally pasteurised products. The use of PEF has no negative effects on aroma and flavour, which means that chilled orange juice, for example, retains its fresh taste over a longer period of time. The valuable ingredients, such as vitamins or polyphenols, are also not affected by the PEF treatment. By using PEF as a preservation method, it is possible to give chilled juices a longer shelf life (see Figure 6) without compromising quality.

Extraction of valuable components

The process step of extracting value-adding components is used in many food production processes. Successful extraction involves a high yield with as little mechanical, thermal and chemical effort as possible. Cell disruption is one of the most important sub-processes. Traditionally, cell disruption, e.g. of plant material, is achieved by mechanical comminution or the addition of enzymes. These processes often lead to undesirable side effects or insufficient yields. An alternative to these methods is the application of PEF. The effect on mass transfer caused by electroporation makes it possible to achieve high yields without the addition of reagents. Many valuable components, such as pigments, polyphenols, sugars, proteins, vitamins, oils and flavours can be gently extracted from a wide variety of raw materials.

In addition to increased yields, downstream processes, such as pressing, can be carried out more efficiently as process temperatures and times can be reduced. As shown in Figure 7, for example, the highest apple juice yield is achieved through PEF treatment compared to the untreated control or enzyme treatment. The pressing system has a significant impact on the increase in yield. The cell disruption results in a softening of the product, which can block the press under certain circumstances. It is therefore important to consider the entire process when integrating PEF technology.

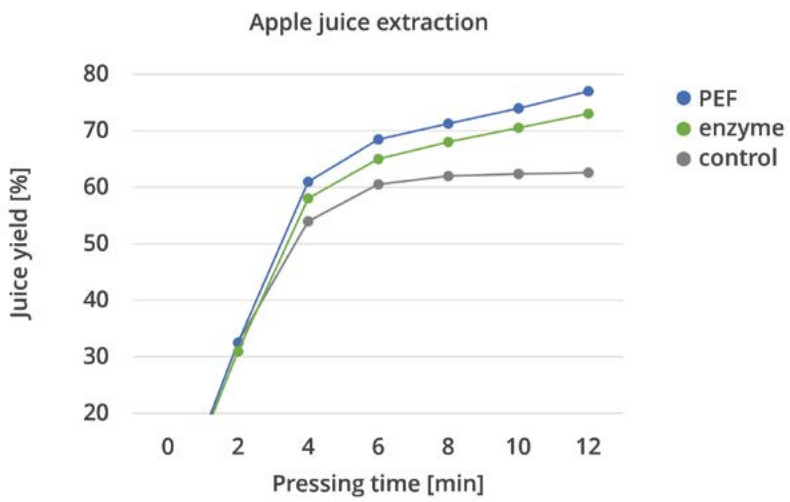

Figure 7: Influence of PEF and enzyme treatment on apple juice yield.

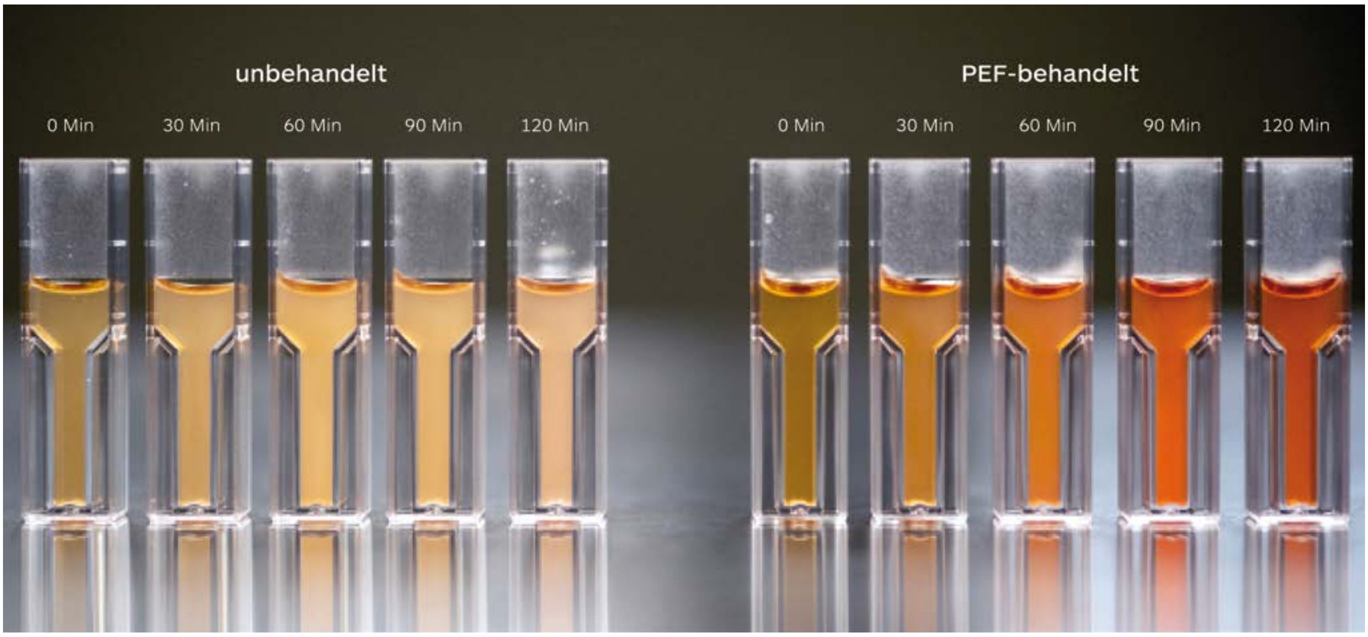

Figure 8: Influence of PEF on the concentration of polyphenol in wine.

Wine

PEF treatment can be used at various points in the complex wine production process. The production process generally comprises the following steps: separation of the grape stems and crushing, maceration, pressing, fermentation, preservation and bottling. During maceration, important quality-determining ingredients such as polyphenols, which are responsible for the red colour, are extracted. This process usually takes about 10-12 days for the production of red wine. After crushing, the grape mash can be subjected to a PEF treatment before maceration. This opens the grape cells and facilitates the exchange of substances. Accordingly, the required polyphenols can be extracted more easily and quickly, reducing the maceration time to 5-6 days. Figure 8 clearly shows that the samples treated with PEF have a more reddish colour, which indicates a higher polyphenol concentration. The reduced maceration time is accompanied by an increase in capacity and energy savings.

After pressing, yeast cultures are added to the grape juice for fermentation of usually 180 days. The added cultures break down the sugar and convert it into alcohol. Another important process during fermentation is the autolysis of the yeast cells, which releases important flavour compounds that have a significant influence on the mouthfeel. Mannoproteins released from the cell wall are one of the most important components here. Studies have shown that PEF treatment of the mash leads to an accelerated release of mannoproteins. The maximum concentration of mannoproteins is reached after just 30 days. Accordingly, the fermentation time can be reduced to 30 days while maintaining the highest quality standards. Conventionally, the addition of sulphur dioxide is often used during fermentation to suppress the growth of undesirable germs, among other things. Treating the wine with PEF makes it possible to kill harmful microorganisms without the addition of additives or temperature treatment.

The PEF process has been officially accepted by the International Organisation of Vine and Wine (OIV) as a cell disruption process. Specifically, PEF treatment can be used as a digestion process for red and white wine in order to simplify and accelerate the extraction of valuable components.

Olive oil

Olive oil is a very valuable natural product that must be carefully produced to ensure high quality. The highest quality oil is the so-called extra virgin olive oil (EVOO). During its production, the temperature must not exceed 27°C and no enzymes are allowed for cell disruption. The most important process steps in production are malaxation and pressing. During malaxation, the olive pomace is stirred to extract the oil from the cells, which is then pressed out. For low-grade oil, enzymes are added to the pomace before malaxation in order to open the cells and increase the yield accordingly. The use of PEF is a gentle alternative to the use of enzymes. The PEF treatment of the pomace opens up the olive cells without the influence of temperature and/or chemicals, which means that the malaxation time and temperature can be reduced.
The cell disruption induced by PEF also facilitates the extraction of polyphenols. After pressing, the oil yield is 90-93% compared to 80% yield without the use of PEF. This corresponds to an increase in yield of 10-13%. In a sensory comparison, the PEF-treated olive oil was described as more fruity and full-bodied. To summarise, PEF treatment represents a good opportunity to make the manufacturing process a more efficient and energy-saving operation and to improve yield and quality.

Figure 9: Industrial PEF unit installed in a Greek olive oil factory.

Use in biotechnology

Many valuable nutrients, such as proteins or essential fatty acids, can be obtained from microorganisms such as yeasts and microalgae. They have many advantages over plants or animals as they are able to utilise inexpensive source materials and waste as carbon and energy sources for the production of biomass. Effective cell disruption is necessary to maximise the concentration of nutrients contained in the cells. Numerous cell disruption methods already exist, but these are often energy-intensive and have a negative effect on the quality of the target substance. PEF can be used here as an energy-saving alternative. One example of the use of PEF to extract valuable components is yeast. Yeasts are used in various fields such as the brewing industry. Partly also as a by-product, yeast is important for the food industry due to its components. By using PEF, valuable ingredients such as flavours, proteins or minerals can be extracted from the yeast cells in an efficient and gentle manner. The promising potential of PEF for the extraction of valuable ingredients is also evident in the field of microalgae. Microalgae are seen as a promising and sustainable source of bioactive compounds, proteins and pigments that are used in the food and health industries. Cell disruption using PEF extracts proteins or colourants such as phycocyanin from spirulina algae. In addition, the PEF process enables a selective extraction of phycocyanin, which leads to a higher purity compared to the use of ultrasound, for example. This in turn results in an increase in the quality of the pigment, which means that additional purification steps are no longer necessary. By adjusting the PEF process parameters, a so-called stress response can be achieved in microorganisms. This is beneficial for fermentations because microorganisms with increased metabolic activity react to the electrical pulses and accordingly show accelerated growth and/or form intracellular components in higher concentrations. Examples of this could be microalgae or starter cultures for various food products such as yoghurt or salami.

Use of PEF in the meat processing industry

The application of PEF for meat and its derivatives offers many possible applications and advantages. These range from tenderising meat and improving the cut appearance to the accelerated absorption of brines and marinades as well as process optimisation in the production of raw sausages and ham. In principle, PEF can be applied to any cut of meat and any species, and the time of the treatment depends on the desired objective. Even meat with a high collagen content, such as beef brisket, can be transformed into tender steaks using PEF without the need for additives, tenderisers, chemicals or heavy mechanical processing. The cutting force can be reduced by 17%. The use of PEF in conjunction with tumbling leads to considerable time and energy savings as well as improved brine absorption. This enables the systems to be refilled sooner and increases capacity. In the production of raw sausages, PEF treatment can accelerate fermentation, reduce the drying time and enable breakage-free slicing without affecting the taste or colour.

Equipment design

PEF systems are available on an industrial scale. Depending on the application, there are continuous belt systems for solid materials or pipe systems for liquid, pumpable products. In general, a PEF system consists of a voltage generator to produce the high-voltage pulses and a treatment unit that is in direct contact with the product and delivers the electrical pulses to it. Among other things, the largest systems can process 100 tonnes of solids (Figure 10) or 5000 litres of liquid per hour.

Figure 10: The largest system can treat up to 100 tonnes per hour.

Summary

PEF treatment is used in the food industry for the targeted disruption of membranes of biological cells and microorganisms. It facilitates the mass transport of cell water as well as valuable substances from the cells. This benefits the potato and vegetable industry in terms of processing and product quality. It is also easier to extract valuable substances, e.g. in the juice industry.

The use of PEF to inactivate microorganisms makes it possible to produce microbiologically stable juice without any loss of quality. The microorganisms are inactivated, the thermal load on the product is low and there are substantial quality benefits in terms of flavour and vitamin content.

To summarise, it can be seen that pulsed electric field technology is used in various areas of the food industry for a wide range of products such as potatoes, vegetables, fruits and meat, but also in biotechnology. The possible benefits of PEF treatment can be found in the specific area of the respective process, e.g. energy savings, and in terms of product quality, e.g. flavour and texture.

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