PEF applications in food industry

Food process	Principle	Food matrix	Advantages /Disadvantages	TRL	Reference
Extraction	Mass transfer process	Juice extraction (apple, carrot, sugar, beet, orange, grapes, mango, olive and sugar beet)	Advantages: Reduction of maceration times Yield improvement Energy savings Increase of antioxidant capacity Better sensory and nutritional quality No thermal effect Tissue softening Limitations: No enzymatic inactivation High industrial rate of production	9	[1–4]
		Microbial biomass (bacteria, yeast, and microalgae): macronutrients (protein, carbohydrates, and lipids); pigments (carotenoids, chlorophylls, and phycobiliproteins); enzymes (β-glucosidase, pullulanase, α-amylase)	Advantages: Yield improvement Higher purity Non-destructive Substitution of detrimental chemical solvents with green solvents No thermal effect Low operation cost Easy to scale up Limitations High cost of the equipment Dependence on medium composition (conductivity)	9	[5]
		Food waste (peel, seeds, leaves)	Advantages: Yield improvement Limitations: Depending on the compound to be extracted and the food waste, it is necessary to adapt the conditions	2	[6,7]
Microbial inactivation	Liquid pasteurization	Liquid food (juices, liquid egg, milk)	Advantages: Mild-pasteurization Better organoleptic and nutritional quality Energy saving Limitations Mild temperatures are necessary to achieve a inactivation of 5 CFU No inactivation of spores Not possible in solid foods	9	[4,8]

Food process	Principle	Food matrix	Advantages /Disadvantages	TRL	Reference
Enzyme deactivation	Protein unfolding and denaturation	Liquid food (juices, liquid egg, milk)	Advantages: No temperature increase Limitations: Higher energy levels are needed than those required for microbial inactivation Some enzymes are activated, other deactivated	2	[9]
Drying	Mass transfer process	Fruit, vegetables, meat products	Advantages: Enhance drying efficiency Reduce drying temperature Increase in moisture diffusivity Higher rehydration capacity Lower shrinkage Higher retention of nutritional compounds Preservation of flavor and taste Limitations: The processing parameters must be very well adjusted according to the type of product	7	[10,11]
Freezing/Thawing	Favors the formation of many small ice crystals	Apple, carrot, potato, spinach, onion, salmon, pork, beef.	Advantages: Shorten freezing and thawing time Smaller ice crystal Improved texture quality when combining PEF with cryoprotectants Limitations: Promotes oxidation processes	2	[4,12]
Cutting	Softening of the tissue	French fries	Advantages: Breaking loss decreased Less feathering Lower starch loss Reduction of fat uptake No effect on rheological characteristics Lower energy consumption Limitations:	9	[13]
Frying	Enhance mass and heat transfer processes	Potato, onions, carrots	Advantages: Significant oil reduction Higher water removal Lower acrylamide content Limitations: Possible oxidation promotion	9	[14]
Peeling	Softening of the tissue	Tomato	Advantages: Reduction of steam used for peeling No effect in texture Lower energy consumption Limitations:	8	[15,16]

Food process	Principle	Food matrix	Advantages /Disadvantages	TRL	Reference
Meat tenderization	Acceleration of proteolysis	Beef *M. longissimus lumborum* muscles	Advantages: No lipid oxidation Reduction in the shear force Limitations: Conclusions are not clear, more studies are needed	3	[17]
Ohmic heating	Joules' effect	Technical agar	Advantages: Fast and volumetric heating of solid foodstuffs Low energy cost Limitations: Presence of cold spots in the vicinity of the sample with the electrodes. More studies are needed	1	[18]

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References:

1. Maza, M.; Álvarez, I.; Raso, J. Thermal and Non-Thermal Physical Methods for Improving Polyphenol Extraction in Red Winemaking. *Beverages* **2019**, *5*, 47, doi:10.3390/beverages5030047.
2. El Kantar, S.; Boussetta, N.; Lebovka, N.; Foucart, F.; Rajha, H.N.; Maroun, R.G.; Louka, N.; Vorobiev, E. Pulsed Electric Field Treatment of Citrus Fruits: Improvement of Juice and Polyphenols Extraction. *Innovative Food Science & Emerging Technologies* **2018**, *46*, 153–161, doi:10.1016/j.ifset.2017.09.024.
3. Veneziani, G.; Esposto, S.; Taticchi, A.; Selvaggini, R.; Sordini, B.; Lorefice, A.; Daidone, L.; Pagano, M.; Tomasone, R.; Servili, M. Extra-Virgin Olive Oil Extracted Using Pulsed Electric Field Technology: Cultivar Impact on Oil Yield and Quality. *Front. Nutr.* **2019**, *6*, doi:10.3389/fnut.2019.00134.
4. Barba, F.J.; Parniakov, O.; Pereira, S.A.; Wiktor, A.; Grimi, N.; Boussetta, N.; Saraiva, J.A.; Raso, J.; Martin-Belloso, O.; Witrowa-Rajchert, D.; et al. Current Applications and New Opportunities for the Use of Pulsed Electric Fields in Food Science and Industry. *Food Research International* **2015**, *77*, 773–798, doi:10.1016/j.foodres.2015.09.015.
5. Martinez, J.M.; Delso, C.; Alvarez, I.; Raso, J. Pulsed Electric Field-Assisted Extraction of Valuable Compounds from Microorganisms. *Comprehensive Reviews in Food Science and Food Safety* **2020**, *19*, 530, doi:10.1111/1541-4337.12512.
6. Arshad, R.N.; Abdul-Malek, Z.; Roobab, U.; Munir, M.A.; Naderipour, A.; Qureshi, M.I.; El-Din Bekhit, A.; Liu, Z.-W.; Aadil, R.M. Pulsed Electric Field: A Potential Alternative towards a Sustainable Food Processing. *Trends in Food Science & Technology* **2021**, *111*, 43–54, doi:10.1016/j.tifs.2021.02.041.
7. Xi, J.; Li, Z.; Fan, Y. Recent Advances in Continuous Extraction of Bioactive Ingredients from Food-Processing Wastes by Pulsed Electric Fields. *Critical Reviews in Food Science & Nutrition* **2021**, *61*, 1738–1750.
8. Toepfl, S.; Heinz, V.; Knorr, D. Applications of Pulsed Electric Fields Technology for the Food Industry. In *Pulsed Electric Fields Technology*

for the Food Industry.; Raso, J., Heinz, V., Eds.; Springer: New York, 2006; pp. 197–217.
9. Martín-Belloso, O.; Elez-Martínez, P. Enzymatic Inactivation by Pulsed Electric Fields. In *Emerging Technologies for Food Processing*; Sun, D.-W., Ed.; ElServier: California, 2005; pp. 155–182.
10. Bassey, E.J.; Cheng, J.-H.; Sun, D.-W. Novel Nonthermal and Thermal Pretreatments for Enhancing Drying Performance and Improving Quality of Fruits and Vegetables. *Trends in Food Science & Technology* **2021**, *112*, 137–148, doi:10.1016/j.tifs.2021.03.045.
11. Astráin-Redín, L.; Raso, J.; Cebrián, G.; Álvarez, I. Potential of Pulsed Electric Fields for the Preparation of Spanish Dry-Cured Sausages. *Scientific Reports* **2019**, *9*, doi:10.1038/s41598-019-52464-3.
12. Li, J.; Shi, J.; Huang, X.; Zou, X.; Li, Z.; Zhang, D.; Zhang, W.; Xu, Y. Effects of Pulsed Electric Field on Freeze-Thaw Quality of Atlantic Salmon. *Innovative Food Science & Emerging Technologies* **2020**, *65*, 102454, doi:10.1016/j.ifset.2020.102454.
13. Fauster, T.; Schlossnikl, D.; Rath, F.; Ostermeier, R.; Teufel, F.; Toepfl, S.; Jaeger, H. Impact of Pulsed Electric Field (PEF) Pretreatment on Process Performance of Industrial French Fries Production. *Journal of Food Engineering* **2018**, *235*, 16–22, doi:10.1016/j.jfoodeng.2018.04.023.
14. Ostermeier, R.; Hill, K.; Dingis, A.; Töpfl, S.; Jäger, H. Influence of Pulsed Electric Field (PEF) and Ultrasound Treatment on the Frying Behavior and Quality of Potato Chips. *Innovative Food Science & Emerging Technologies* **2021**, *67*, 102553, doi:10.1016/j.ifset.2020.102553.
15. Andreou, V.; Dimopoulos, G.; Dermesonlouoglou, E.; Taoukis, P. Application of Pulsed Electric Fields to Improve Product Yield and Waste Valorization in Industrial Tomato Processing. *Journal of Food Engineering* **2020**, *270*, 109778, doi:10.1016/j.jfoodeng.2019.109778.
16. Pataro, G.; Carullo, D.; Bakar Siddique, M.A.; Falcone, M.; Donsì, F.; Ferrari, G. Improved Extractability of Carotenoids from Tomato Peels as Side Benefits of PEF Treatment of Tomato Fruit for More Energy-Efficient Steam-Assisted Peeling. *Journal of Food Engineering* **2018**, *233*, 65–73, doi:10.1016/j.jfoodeng.2018.03.029.
17. Gómez, B.; Munekata, P.E.S.; Gavahian, M.; Barba, F.J.; Martí-Quijal, F.J.; Bolumar, T.; Campagnol, P.C.B.; Tomasevic, I.; Lorenzo, J.M. Application of Pulsed Electric Fields in Meat and Fish Processing Industries: An Overview. *Food Res Int* **2019**, *123*, 95–105, doi:10.1016/j.foodres.2019.04.047.
18. Ariza-Gracia, M.Á.; Cabello, M.P.; Cebrián, G.; Calvo, B.; Álvarez, I. Experimental and Computational Analysis of Microbial Inactivation in a Solid by Ohmic Heating Using Pulsed Electric Fields. *IFSET* **2020**, *65*, 102440, doi:10.1016/j.ifset.2020.102440.