

## Trends and expected benefits of the breaking edge food technologies in 2021–2030

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### Abstract

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**Introduction.** The review considered the major trends in the world development of new food processing technologies in 2021–2030 that are as follows:

**Material and method.** Morphological analysis of clusters of scientific knowledge about food science.

**Result and discussion.** Major trends in the world development of new food processing technologies:

1. More strict regulations of food safety including QPCR and DNA-sequencing detection of emerging food-borne pathogens, comprehensive control of minor chemical pollutants of food;

2. Production of functional food including food for babies, children, pregnant women, elderly, for sport activities, military food, meals ready-to-eat, microelements-enriched food, nutraceuticals, and clinical food;

3. Emerging environmentally-friendly and energy-saving food processing including non-thermal physical methods such as cold plasma processing, high pressure homogenization, pulsed electric fields, ultrasound-assisted extraction, novel food-drying technologies, novel ethanol production technologies, novel extraction technologies, disinfection and sterilization of food and equipment, novel food packaging technologies, food processing intensification using biotechnological methods, involvement of new food staff and materials for food production;

4. Biotechnological food processing using enzymes proteinases, glutamine transferases, galactosidases, enzymes of extremophilic and psychrophilic microorganisms, alive microorganisms as probiotics or starter cultures, microbial metabolites, and new sources of food such as insects and artificial meat;

5. Personalization of food processing and distribution including adaptation of the food processing to the nutritional needs of the different medical, racial, religious, and regional customer groups, computerization of the personal food production and consumption, and a problem of consumer acceptance of a new food, 3D printing of personal food. Commercial food became so diverse that the specific nutritional computer programs with the comprehensive information on this food as well as personal diet requirements will be used for the optimization of the production and delivery of the personal-specified food.

**Conclusions.** Review information can be valuable for researchers and managers to prioritize the research and innovation directions.

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## **Trend 1. Enhanced food safety**

### **Food safety regulations**

Development of new food technologies increases the risk of the foodborne diseases and food contamination. For example, about 48 million people in U.S. get sick and 3,000 die each year from foodborne diseases (CDC, 2018). In Europe, there are 23 million cases of foodborne diseases causing 5,000 deaths every year by WHO estimation (Flynn et al., 2019).

Food is an essential source of human exposure to harmful for health chemicals. Food contamination is also increasing, for example in U.S. more than half of the foods tested had pesticide residues. Therefore, new and more strict regulations for the food manufacturers and distributors were established there by the shifting of the focus from responding to prevention of foodborne illness (Food Safety Modernization Act, 2020). The main idea of this legislation is that prevention of foodborne illness and food contamination is both a significant public health problem and a threat to the economic well-being of the food system. So, food industry executives have to make sure their enterprises are complying with the latest regulations to ensure food quality from farm to fork.

Current rules and related programs of Food Safety Modernization Act (FSMA) are as follows:

1. Accredited third-party certification;
2. Current good manufacturing practice, hazard analysis, and risk-based preventive controls for human food;
3. Current good manufacturing practice, hazard analysis, and risk-based preventive controls for animal feed;
4. Foreign supplier verification programs;
5. Laboratory accreditation;
6. Food traceability;
7. Mitigation strategies to protect food against intentional adulteration;
8. Sanitary transportation of human and animal food;
9. Standards for the growing, harvesting, packing, and holding of produce for human consumption;
10. Voluntary qualified importer program (food safety modernization act, 2020).

Food industry needs more scrutiny and transparency because of the inherent risk involved with allowing untested ingredients to enter the market.

Similar activities are performing currently in Europe to enhance transparency and sustainability of the EU risk assessment in the food chain (EU risk assessment in the food chain, 2019). The main points of this regulation are as follows:

1. Ensuring more transparency so that citizens will have automatic access to all studies and information submitted by industry in the risk assessment process;
2. Increasing the independence of studies;
3. Strengthening the governance and the scientific cooperation in eu;
4. Developing comprehensive risk communication throughout the risk analysis process, combined with open dialogue amongst all interested parties.

The National Center for Food Safety Risk Assessment was created in China. It is a key contributor to the food safety standards using international best practices and CODEX ALIMENTARIUS of FAO-WHO (Zhang et al., 2018; The Codex Alimentarius, 2020). The center comprises four networks of food safety in China including the foodborne disease surveillance network, the biological hazards (bacteria, viruses and parasites) monitoring in

foods network (Pei et al., 2015), chemical hazards monitoring in foods network, and the microbial DNA fingerprint profile network (Wu and Chen, 2018).

The Codex Alimentarius of FAO-WHO (The Codex Alimentarius, 2020) considers such important standards of food safety as:

1. Quality of animal feed that plays a vital role in the production of safe and quality products of animal origin;
2. Antimicrobial resistance, which is a global threat of increasing concern to human and animal health and the economic wellbeing of farming households;
3. Biotechnology of food, mainly of genetically modified organisms (gmos) and other potentially unsafe biotechnological methods and products;
4. Chemical contaminants of food and feed, especially pesticides, that may pose a risk to animal and human health;
5. Nutrition and labelling ensuring information for the choice of healthy and safe foods.

The types of food safety events were distributed in 2017 as follows: biological (microbiological) hazards – 64%, chemical hazards – 16%, physical hazards – 2%, allergens – 7%, hazards of unknown origin – 11% (WHO/FAO, 2018).

### **Detection of emerging food-borne pathogens**

Data on *Salmonella* isolates in food for 2012 -2016 showed that in 61% cases there were contaminated chicken and chicken products, in 16% cases there were pork and pork products, and only small quantity of beef and eggs, 1.5 and 1%, respectively, were contaminated with *Salmonella* (Schlundt et al., 2020). Using novel methods there were discovered new 175 pathogenic microbiological species considered to be “emerging” (Schlundt et al., 2020) and a lot of them could be the agents of foodborne diseases. Innovative approach in the evaluation of bacteriological safety of food is detection of wide-spread antibiotic-resistant microorganisms (ARM) in food. Resistance of pathogens to antibiotics considered as the greatest and most urgent global risk (UN, 2016).

Analysis of ARM in food is developing in Nanyang Technological University, Food Technology Centre, Singapore by the team of Prof. Jørgen Schlundt (Schlundt et al., 2020). For detection of foodborne pathogen and ARM in food there are used not only conventional microbiological methods but mainly identification and subtyping of isolates of foodborne bacterial pathogens by matrix-assisted laser desorption ionization-time of flight mass spectrometry (Aung et al., 2020) and whole genome sequencing, which is delivering sufficiently high resolution and epidemiological concordance (Schlundt et al., 2020). Whole genome sequencing will be the most advanced method in the nearest future to study food biosafety and foodborne diseases.

Another modern approach to study microbiological safety of food is pulsed-field gel electrophoresis (PFGE), which is a DNA fingerprint for a bacterial isolate. PFGE could be used effectively to investigate bacterial isolates from sick people, the contaminated food, and the sites of food production (Pulsed-field Gel Electrophoresis, 2016).

### **Control of chemical pollutants of food**

Major chemical pollutants of feed and food are as follows:

1. Mycotoxins such as aflatoxins, fumonisins, mycotoxins of *Fusarium spp.* Such as trichothecenes T-2 toxin, HT-2 toxin, deoxynivalenol (DON), nivalenol, zearalenone,

and some other toxins such as ochratoxins of *Aspergillus ochraceus*, *A. Carbonarius*, *A. Niger*, *Penicillium verrucosum*; some substances, for example patulin produced in the rotten apples and extracted to the apple juice, are rather carcinogenic than toxic substances;

2. Polycyclic aromatic hydrocarbons (pahs) such as naphthalene, benzopyrene, chrysene, benz(a)anthracene, and others;
3. Recalcitrant organic pollutants such as aldrin, dieldrin, heptachlor, endrin, DDT, hexachlorocyclohexanes, polychlorinated biphenyls, dioxins, and others. Major part of these pollutants entering human organism with food of animal origin, mainly from beef and dairy food;
4. Hormones in meat that was used as animal growth promoters: oestradiol, testosterone, progesterone, zeranol, trenbolone acetate and melengestrol acetate, and substances having a thyrostatic action and of beta-agonists (EUR-LEX EUROPA; Guide to cross compliance in England, 2020);
5. Chemical food preservatives and other chemical food additives to control ph, foam, oxidation, color, flavor, emulsification, thickening, food energy;
6. Some toxic or carcinogenic substances are producing during food processing, for example, acrylamide that is produced from potato or cereals at temperature above 120 °C;
7. Indirect chemical food additives that are used in food production and packaging from food contact materials (FCM): food containers, processing machinery, packaging materials, kitchenware and tableware (WHO, 2019; EU food chemical safety, 2018). For Ukraine, it is important a problem of high concentration of water-retention substances, phosphates and salt in the meat and meat products, which are increasing a risk of cardiovascular diseases and strokes of people with hypertension (<http://www.ncbi.nlm.nih.gov/pmc/articles/PMC3278747>).

The general trend in USA and in Europe that will be developed in 2021–2030 is strict legislation on authorization, comprehensive testing of safety, and limited use of food chemical additives. For all food contaminants must be established maximum levels to protect public health (WHO, 2019; EU food chemical safety, 2018). The European Commission publishes a factsheet on food contaminants (Managing food contaminants – European Commission, 2007).

Ukrainian food manufacturers are introducing safety control procedures of the Hazard Analysis and Critical Control Point (HACCP) system for correct organization of food production, analysis of reasons for mistakes, and determining methods of fixing them (The system of hazard analysis and critical control points, 2019).

Currently, HACCP systems in Ukraine were implemented only at large, export-oriented enterprises (EU in Ukraine, 2019), so it is a need for wider comprehensive implementation during 2021 – 2030.

## **Trend 2. Functional food and nutraceuticals**

### **Functional food**

Every kind of food has physiological and health effects. For example, consumption of processed meat correlated with the risk of colorectal and stomach cancer, and it was calculated that diminishing of the processing meet consumption in USA using 10% excise

tax would prevent 77,000 colorectal and 12,400 stomach cancer cases and generate net savings of about US\$41 billion from healthcare and societal perspectives (Kim et al., 2019). Modern trend in the food technology is production of the functional food that has scientifically defined and described physiological benefits to consumers (Granato et al., 2020). There are used functional food ingredients such as vitamins, proteins, microelements, polyunsaturated fatty acids, antioxidants, polyphenols, probiotics and prebiotics, fructose, and many others. Functional food is developing and marketed for different age groups, patients with specific diseases, and groups with different nutritional requirements or customs (Bogue et al., 2017).

### **Food for babies and children**

Micro- and macronutrients in the food for babies and children is most important factor of their growth and the development of cognitive and psychomotor skills (Gutierrez, 2020). As shown in the cited book, food industry should develop different infant milk formulas, addition of probiotics and prebiotics, specific baby food from cereals, optimization of micro- and macronutrients for special diet regimes to prevent allergies of babies and children to gluten, casein, phenylalanine, intolerance to lactose, to avoid children obesity, and many other specific dietary requirements for babies and children.

So, differentiation and development of functional food for babies and children will remain one of the major trends in the food technologies in 2021–2030.

### **Food for pregnant women**

Food for the vulnerable population of pregnant women is not differentiated too much but there are strict requirements for food safety (Flynn et al., 2019), food avoidances, food additions like protein, iron, folate, and fiber (Siega-Riz et al., 2002), 50 types of food taboos for pregnant women in some countries (Iradukunda, 2020).

So, there are a lot of opportunities for the development and commercialization of new kinds of food for the pregnant women.

### **Food for elderly people**

Food for elderly people should be personalized because their nutrition is age-specific, their food choice is mediated by medicine and health-related public information (Herne, 1995), and there are numerous factors important for health of elderly people (Rusu et al., 2020). This food must be personalized by the content of macro- and micro-components that is adapted to personal age-related diseases. The texture of food should be adapted to the chewing and swallowing problems. The food taste should be personally adapted because it is changed with ageing (Laureati et al., 2006). Even in developed countries, significant part of elderly long-term-care home residents are malnourished (Nieuwenhuizen et al. 2010) due to physiological and psychological problems with not personalized food (Rusu et al., 2020).

So, development of food for elderly people should be done as a personalized food or at least as food for the groups of elderly people differentiated by the medical indications.

### **Food for sportsmen**

It is well known that dietary supplements are very popular in sport diet and the doses of these supplements are higher than in the normal diet (Burke and Read, 1993). Sport food

provides enhanced consumption of special nutrients or just more convenient consumption of nutrients for athletes. Very popular is also a sport drink, which is usually balanced by carbohydrates and salts. For example, solution containing glucose, maltodextrins, and electrolytes are suitable for sport activity sources of water, energy, and optimal dosage of potassium and sodium ions to avoid dehydration and at the same time an intestinal absorption of water (Burke and Read, 1993). Another type of a sport drink is a solution containing up to 25% of carbohydrates to support high carbohydrate intake by the athletes. There are used also in sport diet the liquid meals with essential components, for example iron, vitamins, and easily digested components for consumption at conditions when it is not suitable consume the solid food. It is clear that the production and consumption of the food developed for specific sport activity will be increased in 2021–2030.

### **Military food and ready-to-eat meals**

The major trend in military food is production of diverse, specialized or the type of military activity “Meals, Ready-to-Eat” (MREs) including not only food and drinks but also flameless heater and accessories. A MRE contains usually one-third of the Military Recommended Daily Allowance of proteins, carbohydrates, fat, vitamins, and minerals containing 1,250 calories, 13% protein, 36% fat, and 51% carbohydrates (Scott and Albert, 2006). In USA, soldiers can choose from up to 24 entrees, and more than an additional 150 items in the MRE chain and a minimum shelf life at 27 °C is 3.5 years (<https://www.goarmy.com/soldier-life/fitness-and-nutrition/components-of-nutrition/meals-ready-to-eat.html>). MREs should be developed and produced also for civilians: refugees from violence or military actions region, those who is suffering from poverty, population in the area of natural disaster or great industrial accident, the travelers in air and on land, or just those who prefer to it MRE. There is also known set “First Strike Ration” (FSR) that is used for the whole day and twice easier MRE ([https://www.gaydamak.com.ua/suhpaj-armii-ssha-first-strike-ration-sus\\_24-ru](https://www.gaydamak.com.ua/suhpaj-armii-ssha-first-strike-ration-sus_24-ru)).

Food for Ukrainian soldiers is cooked and supplied by catalogue. There is also used “Daily set of food” or “Suhpay” (“Dry meals” in English) that means set of dry food” ([https://portion.com.ua/category/nabory](https://portion.com.ua/category/nabory;); [reibert.info/lots/sutochnyj-polevoj-nabor-produktov-dpnp-p-1-s.309448](http://reibert.info/lots/sutochnyj-polevoj-nabor-produktov-dpnp-p-1-s.309448)). However, increase of the production and using of the MREs in Ukraine could be useful not only for the military personnel, but also for civilians, for example travelers. Just for Ukraine, abbreviation of this type of food must be not “MRE” because it means in Ukrainian “Dying”, but may be better use something like REM, “Ready-to-Eat Meals”.

It could be also commercially viable if the food industry will start production of the diverse, tasty, low-calorie menu of MREs that will restrict intake to approximately 1,400 calories per day for men, and to 1,200 calories per day for women.

So, production of diverse MREs in Ukraine should be widely developed in food industry during 2021–2030.

### **Microelements-enriched food**

Proper nutrition includes recommended daily allowance of essential and probably essential microelements (WHO, 1996) such as zinc, iron, manganese, copper, chromium, iodine, fluorine, selenium, molybdenum, boron, chlorine, nickel, silicon, sodium, cobalt, and strontium (Nieder et al., 2018; WHO, 1996; Mehri, 2020). For example, trivalent chromium is essential for diabetic patients receiving parenteral nutrition; copper and especially zinc are

included in the activity center of many enzymes; selenomethionine and selenocysteine from food participate in the immune responses; thyroid functions, and reproduction; four human enzymes requiring molybdenum as cofactor; iodine is an essential for the functioning of the thyroid hormones; iron and manganese are the essential elements being a component of many metalloenzymes; essential silicon is supplied mainly with the plant foods (Mehri, 2020).

Support of the microelements levels in an organism can be done using dietary diversification, food fortification, and increasing content or availability of microelements in food products. Current and developing trend in the production of the functional foods enriched with microelements is an addition of fruits and vegetables, edible mushrooms, biomass of seaweeds, cultivated microscopic algae, yeasts, or bacteria to conventional food to optimize the content of microelements, as well as vitamins. The food additions and food compositions must be specific for the regions and the customer groups. Usually, the dominant elements to fortify food are iron, calcium, zinc and iodine (Gharibzadeh and Jafari, 2017).

Trace essential elements added to the food can be toxic elements depending on the dosage. Therefore, the food fortification with microelements, vitamins, other food additives must be under strict and obligatory regulations on their content and forms in food (Konikowska and Mandecka, 2018; Poniedziałek et al., 2020).

So, production of microelements-enriched food and nutraceuticals with microelements and vitamins in Ukraine should be widely developed in food industry during 2021–2030.

### **Selenium-enriched food**

Selenium is an essential microelement being cofactor of many enzymes, which are participating in antioxidant defense, immunomodulation, thyroid functioning, and sperm motility (Kora, 2020). Meanwhile, diet in some regions is deficient in selenium. For example, bread enriched with biomass of yeast or plant sprouts with increased content of organic forms of selenium is recommended for the population of North Ukraine, Belorussia, and Poland where acidic soil diminished the content of organic forms of selenium in cereals (Stabnikova et al., 2005; 2008; 2019). Therefore, supplementation of the food with organic form of selenium became a trend in food industry of many countries (Yang and Dong, 2017; Kieliszek, 2019). However, because of the narrow gap between recommended consumption dosage and toxic dosage of selenium and some other microelements it could be better to produce and consume such microelements as nutraceuticals, see below.

Good source of organic forms of selenium as well as other macro- and microelements, antioxidants, vitamins, dietary fibers, unsaturated fatty acids is the biomass of edible fungi (Kora, 2000), biomass of yeasts (Stabnikova et al., 2005; 2008). biomass or extracts of edible seaweeds, which are intensively studied as a functional food addition (Roohinejad et al., 2017; Shennon and Abu-Ghannam, 2019; Corsetto et al., 2020). Kappa carrageenan, agar, alginate and other gelling substances from seaweeds are also used in foods (Rhein-Knudsen et al. 2015; Zollman 2019). It is expected that applications of seaweeds and their components in food technologies will be increased especially in case if seaweed harvesting will be increased on the Pacific seashores of Chili, Canada, and Russia.

### **Nutraceuticals**

Nutraceuticals is a food with some physiological benefits and manufactured usually as the pharmaceutical product, *i.e.* as the capsules, pills, or extracts with clearly defined dosage of pure or at least determined biologically active substances. They are used as dietary

supplements, dietary nutrition for chronic diseases (gastrointestinal, diabetes, cancer) and for clinical nutrition.

Important direction in nutraceuticals is production of nutraceutical lipids (Akoh et al., 2017). Lipospheres are used in medicine for drug delivery (Bunjes, 2005). So, preparation of the colloidal lipid nanostructures, usually from phospholipids forming bilayer structures, and the preparation of the nanoparticles of encapsulated or solubilized hydrophobic bioactive compounds (Akhavan et al., 2018; Babazadeh and Ghanbarzadeh, 2017; Huang et al., 2017; Santos et al., 2019) could improve bioaccessibility of the lipids, protect them from oxidation, and fortify the food, for example with lipophilic vitamins or with omega-3 fatty acids (Awad et al., 2009; McClements, 2018). This is very popular direction in nutraceuticals. Lipid-containing nutraceuticals are prepared very often with lycopene, other carotenoids, or quercetin to increase shelf-life of the unsaturated fatty acids of lipids (Huang et al., 2017; Zardini et al., 2018). Lipid-based nutraceuticals can be considered as food that is preventing disease due to anti-inflammatory, wound healing, and other medicinal effects (Shin et al., 2015).

The biomass of seaweeds or their extracts are widely used for production of nutraceuticals. It is known that countries with regular consumption of seaweeds by population have significantly lower than average frequency of dietary-related disease such as type 2 diabetes and obesity as well as some types of cancer (Shannon and Abu-Ghannam, 2019). The seaweed extract increased the oxidative stability of fish oil-loaded capsules with dextran as the main biopolymer wall material (Hermund et al., 2019).

Generally, nutraceuticals are a type of the functional food and should be developed and manufactured on the modern food processing plants in 2021–2030.

### **Trend 3. Environmentally-friendly and energy-saving food processing**

#### **Emerging non-thermal and energy saving processing**

There are intensively developing novel food processing technologies that are environmentally-friendly and energy-saving ones. For example, developing of modern food processing technologies limiting the thermal degradation of the biologically active compounds and saving taste and aroma of food are based on cold plasma, pressurized fluids, pulsed electric fields, ohmic heating, radiofrequency electric fields, ultrasonics and megasonics, high hydrostatic pressure, high pressure homogenization, hyperbaric storage, and negative pressure cavitation extraction (Misra et al., 2017). These processes can be not only fast, environmentally-friendly and energy-saving but also can ensure food safety and high nutritional value (Misra et al., 2017).

#### **Cold plasma processing**

Plasma is ionized gas containing electrons, ions, neutral molecules, and atoms. A high-temperature plasma is a fully ionized one but in non-thermal, partially ionized temperature plasma remains so low that can be used in biological applications (Sakudo et al., 2019; 2020). Cold plasma is a useful method for inactivation of microorganisms of meats and vegetables, microflora of milk and dairy products, browning enzymes polyphenoloxidase and peroxidases, thus improving food preservation (Thirumdas, 2015; Misra et al., 2016; Coutinho et al., 2018). Cold plasma inactivates the microbial contaminants on both animal and plant food for 3 – 120 s by  $10^5$  magnitude. It is due to UV light and chemical products



that are accompanying ionization (Niemira, 2012; Pankaj et al., 2018). It can be used also for decontamination of food packaging materials (Pankaj et al., 2014). However, there are still challenges in application of this technology in food industry such as regulatory approval, design of the plasma source, and process control (Keener and Misra, 2016).

### **High pressure homogenization**

Batch or continuous high pressure (HPH, 100–300 MPa) or ultra-high pressure (UHPH, 300–450 MPa) homogenization is performing due to flow of a pressurized fluid through a system that produce strong turbulence, cavitation, and temperature increase. This treatment repeated 5–10 times enhances emulsion stability, diminishes particle size, increases availability of nutritional components, and inactivates microbes (Martínez-Monteagudo et al., 2017; Sevenich and Mathys, 2018; Levy et al., 2020). It can be used also for extraction of bioactive compounds from the foodstuff or food processing waste (Juric et al., 2019), modification of rheological properties of biopolymers (Xie et al., 2018), and food sterilization (Sevenich and Mathys, 2018). However, processing cost of HPH and UHPH is relatively high, from 0.5 to 1.5 €/kg and processing rate is relatively low, approximately 264 kg/h for a system with 55 L vessel (Sevenich and Mathys, 2018). Additionally, food processing regulations in EU (EC No.258/97) requires that each food treated with HPH or UHPH needs to be tested is there equivalent to an existing food in the EU or not (Sevenich and Mathys, 2018).

### **Pulsed electric fields**

Pulsed electric fields (PEF) is a new non-thermal food processing and preservation technology that is acting on cells due to electroporation of cell membrane (Saulis, 2010). It is a non-thermal method that does not deteriorate food quality (Mohamed and Eissa, 2012; Barbosa-Cánovas and Zhang, 2019). Pulsed electric field treatment has positive effect not only for the food pasteurization but also for the extraction, for the drying through decreasing drying temperature or decreasing freezing time (Barba et al., 2015; Sitzmann et al., 2016). Useful food processing technology could be PEF-assisted cold pasteurization of liquid foods (Sitzmann et al., 2016).

### **Novel extraction technologies**

Ultrasound-assisted extraction (UAE) acting by production of the cavitation bubbles in biomaterials is used for in food processing nutraceuticals, methane biogeneration and other biorefinery processes from food and agricultural wastes (Chemat et al., 2017; Wen et al., 2018; Martínez-Patiño et al., 2019). The benefits of UAE are fast extraction, low consumption of energy, and improvement in bioavailability of food components. It is most applicable in extraction of oil, proteins, polysaccharides, polyphenols, natural colorants such as anthocyanin (Pinela et al., 2019), antioxidant phenolic compounds from different plant materials (Chen et al., 2018; Görgüç et al., 2019; Sharaye et al., 2019; del Mar Contreras et al., 2020). UAE is used as a pre-treatment step in the processing of plant-based food, mainly of high-cost raw materials (Vilkhu et al., 2008) and for the extraction of thermo-labile compounds (Medina-Torres and Ayora-Talavera, 2017; Jalili et al., 2018).

There are known also other “green” extraction methods such as microwave-assisted extraction, high-pressure assisted extraction, high voltage electric discharges assisted extraction, pulsed electric fields assisted extraction, supercritical fluids extraction with low

expenditure of energy and solvents (Putnik et al., 2018). These methods are useful for lower cost, non-thermal extraction of biologically active compounds for example antioxidant phenols, vitamins, carotenoids, essential oils, phytosterols, antimicrobial compounds from fruits, berries, and vegetables in production of nutraceuticals and non-caloric sweetener from *Stevia rebaudiana* (Putnik et al., 2018). Natural antioxidants like polyphenols are often extracted from the berries wastes, grape pomaces, citrus and pomelo waste, and use of novel extraction technologies can increase the yield of nutraceutical product by 50%, however industrial innovative solutions for extraction of biologically active compounds are very specific and were not sufficiently tested in food industry yet (Putnik et al., 2018). So, industrialization of these novel extraction technologies is a current task of food sciences.

### **Novel food-drying technologies**

Novel drying technologies such as infrared-assisted freeze drying (Hnin et al., 2019), microwave-assisted convective drying (Kumar and Karim, 2019), and ultrasound-assisted convective drying (Szadzińska et al., 2019) are more energy-saving than conventional freeze drying or convective and often improving food quality. Infrared-assisted freeze drying at 45 – 55°C could save up to 14% of the drying time and up to 19% of the energy compared to conventional freeze drying (Hnin et al., 2019). The drying time was shorter by up to 64% and energy consumption is lower up to 23% for ultrasound-assisted convective drying as compared to convective drying of raspberries (Szadzińska et al., 2019). Energy saving for microwave-assisted convective drying were even higher, up to 54% as compared to convective drying. Biomimetic technologies such as electronic nose and computer vision altogether with artificial intelligence technologies can significantly improve different drying technologies (Sun et al., 2019).

### **Membrane distillation of ethanol**

The conventional distillation and rectification of ethanol produced by yeast fermentation consume tremendous amounts of energy. Therefore, a lot of technologies have been tested to replace conventional distillation and rectification of ethanol by membrane distillation and rectification (Banat and Simandl, 1999; Curcio and Drioli, 2005). For example, with the feed concentration of ethanol 10 % (w/w), at temperature range of 40–70°C, ethanol selectivity was 2–3.5 for PVDF membrane used for water-ethanol separation (Banat and Simandl, 1999). Economic consideration showed that integrating distillation with membrane- based separation can really reduce the ethanol production cost (Gavahian et al., 2019; Khalid et al., 2019). Ohmic-assisted volume heating and distillation of ethanol has such benefits as saving time and energy (Gavahian et al., 2018; 2019). This technology can be used also for essential oil extraction from plants. The ethanol fermentation can be integrated with the membrane distillation of ethanol so that the productivity of fermentation in the membrane bioreactor was 5.5 g of ethanol/L/h instead of 2.6 g of ethanol/L/h in the reactor without membrane distillation (Gryta, 2001)

### **Disinfection of equipment**

For the cleaning and disinfection of food processing equipment, it must be sequentially cleaned, washed, disinfected and rinsed. Novel physical cleaning methods of equipment are dry-ice cleaning, ice-pigging where ice-water mixture is used to remove and carry off particles from equipment, and ultrasonic vibration to clean the membranes that are used for

filtration (Otto et al., 2011). Hydrogen peroxide 5% solution (Moretro et al., 2019) or electrolyzed water (Tango et al., 2019) are both effective in cleaning and disinfection of food-processing equipment. The sterilization of equipment can be done also by heating, using different liquids mainly phenolic or quaternary ammonium compounds, and using such gaseous chemicals as ethylene oxide and hydrogen peroxide vapor (Chauhan and Jindal, 2020).

The cutting-edge advancements in sterilization of food industry equipment came from the space research because spacecrafts must be not contaminated to avoid investigation problems. Initial thermal treatment of the spacecraft equipment was replaced by carbon dioxide snow cleaning, vapor hydrogen peroxide sterilization, and gamma irradiation sterilization (Gradnini et al, 2019). Cold plasma technology can be used to inactivate pathogens on the surface of food processing equipment (Sakudo et al., 2019; 2020; Katsigiannis et al., 2021).

Food processing plants has to be also cleaned or even disinfected to prevent biocontamination of food with the fungal spores, bacterial cells or spores, and viruses. Equipment and technologies for air disinfection are common for all bioaerosols: aseptic filtering through the fibers, hydrophobic membrane filtration, chemical fogging, ozonation, and UV radiation (Masotti et al., 2019).

### **Decontamination of fresh vegetables, fruits, and berries**

To diminish spoilage of the vegetables, fruits and berries and the risk of infectious diseases and helminthosis this production is washed by solution of chlorine that is giving toxic by-products. Now this practice is prohibited in EC and is replaced with decontamination using hydrogen peroxide, ozone, organic acids, as well as irradiation and ultrasound (Meireles et al., 2016; Deng et al., 2020). Biotechnological products such as polysaccharides, biosurfactants, and probiotics can be used to diminish microbial contamination of fresh vegetables and fruits and to increase significantly shelf-life of vegetables and fruits (Pirog et al., 2019; Gregirchak et al., 2020). However, this direction is not developed yet.

The main point of the decontamination studies is to find optimum between maximum of antimicrobial activity and minimum of produce deterioration (Deng et al., 2020).

### **Novel food packaging materials and technologies**

Disinfection of the packed food and packaging materials, for example using cold plasma or the dielectric barrier discharge plasma (Peng et al., 2020), are also important for extended shelf life.

Nowadays the implementation of logistics packaging systems is an integral part of any production of finished products. Packaging turns product into the commodity. To ensure a synergistic connection of three systems – products, packaging materials, packaging machines is the condition for high-quality packaging operations. Each of these systems develops independently, but during packing features and stages of development of other systems are considered (Dudeja et al., 2016).

A lot of innovative food packaging materials are developed using such conditions as to be convenient for packing and distribution, with extended shelf life, maintained good quality of the products (Majid et al., 2018). Absorption of oxygen in the pack is most important for the long-term storage of the food products (Pasichnyi et al., 2018). Disinfection of the packed food and packaging materials, for example using cold plasma or the dielectric barrier discharge plasma (Peng et al., 2020), are also important for extended shelf life.

Food products as objects of packaging must meet all the requirements of consumers and have the properties necessary for the implementation of the certain technologies of packaging, storage, transportation and sale. Different packaging technologies also give different results in terms of product preservation and waste minimization. A packaged product is a single system of interaction between packaging and product. Packaging creates a separate medium which should be safe for storing products. Therefore, the processes of interaction and the formation of barriers take place between the packaging, the product and the medium (. Mannheim et al., 1990; Svensson, 2003). These processes include:

- Biochemical processes in the product;
- Interaction between internal and external media;
- Interaction between the product and the internal medium;
- Penetration of liquids, steam, gas, sunlight and more from the outside;
- Loss of products or its components;
- Interaction between the external medium and the packaging material;
- The influence of the external medium on the packaging material.

The study and research of these processes make it possible to minimize the waste of packaged products.

The efficiency of logistics involves the performance of a significant number of functions that rely on packaging (Aggarwal, 2020). Key features include:

- Operational feature provides protection of packaged products from mechanical and physico-chemical damages;
- Technological feature ensures rational, with minimal losses production, storage and transportation of packaged products;
- Ecological feature provides the use of cheap, environmentally friendly, fast-renewable and affordable packaging materials;
- Special feature depends on the properties of the product, its physical condition, shelf life, consumption conditions;
- Sanitary and hygienic features provide neutrality and safety of packaging for the products.

Along with these functions, today it is important to digitalize packaging, i.e. to create intelligent packaging.

The implementation of the sustainable program involves the development of the packaging industry in the direction of a closed cycle economy. Therefore, an important trend in the development of packaging is environmental safety (Makolli, 2019). During the implementation of the program to minimize the flow of packaging waste and their release into the environment, development priorities should be structured according to the principles of 6R (Szaky, 2019):

- Reduce: reduction of used raw materials;
- Redesign: design and development (or redesign) of packaging for reuse or recycling;
- Remove: exclusion of disposable packaging from the use, where it is possible;
- Reuse: reuse or restoration / repair;
- Recycle: closed cycle recycling, where waste is used in the production of the same packaging;
- Recover: removal of useful chemical components or use as a fuel during combustion to generate heat.

The advanced packaging has to be made from the biodegradable materials, and indicate freshness, retard oxidation, prevent microbial growth, use of ethylene and CO<sub>2</sub> scavengers, time-temperature sensor, and release of antioxidants during storage (Majid et al., 2018).

New but with not clear future is the development of edible food packaging to reduce pollution of environment with million tons of disposed macro-plastic and micro-plastic.

The formation of packaging systems with the packaging-product interaction is carried out in packaging machines.

Modern models of packaging equipment are complex technical systems built on the aggregate-modular principle. The trend of development of packaging machines provides that the latest models of such equipment are integrated technical complexes created on the basis of mechatronic functional modules (Kryvoplias-Volodina, 2018), each of which is both functionally and structurally independent product with a large number of synergistically interconnected characteristics and parameters. implementation of packaging technologies.

In recent years, general trends in the development of technology, which provide the restructuring of all areas of human activity, include the packaging industry (Bigliardi, 2021). These trends were called the "Fourth Industrial Revolution" (Chisenga et al, 2020). Therefore, the current packaging industry is characterized by the active introduction of automated packaging.

Creating a new generation of packaging equipment which has flexible structure and is universal for different types of products and packaging materials is the main task today (Smith et al, 1990). Its solution requires a systematic approach, starting with the development of the concept of design of automated production lines of packaging and ending with the design of the working bodies of machines. Such a concept can be the concept of functionally oriented design using mechatronic modules, which allows to create clusters of functional modules, combine them, create a wide range of parametric series of packaging equipment of one functional purpose with a flexible structure of changes in processes at the automated control system and take into account the features of all stages of the life cycle of machines (Kryvoplias-Volodina. et al, 2019).

Logical design combines possible methodologies, techniques and methods of systems for designing new packaging equipment, providing the growing demands of consumers for its technical capabilities.

## **Trend 4. Biotechnological food processing**

### **Use of enzymes for food processing**

Microbial enzymes are used in the food processing more than 60 years but new enzymatic applications for food processing have been found every year. So, this is a developing area of food science and technology.

The hydrolases, first of all proteinases, are most applicable enzymes in food technology. Proteinases from the calve stomach – chymosin (rennin), pepsin, gastriscin – were used as milk coagulant ("calf rennet") in the cheeses production for centuries (Moschopoulo, 2016). Proteinase from tropical fruit papaya is widely used for meat tenderization and production of protein hydrolysate for a half century (Fernández-Lucas and Castañeda, 2017). However, proteinases from bacteria and fungi have different functions and low cost so they are most widely used at present in food processing industry (Banerjee and Ray, 2017; Kamal et al., 2017; Tavano et al. 2018). Big diversity of proteases is due to their dual participation in metabolism: one part of proteinases control metabolism modifying specific proteins through the hydrolysis of specific peptide bonds, and another part of proteinases degrade proteins for turnover of aminoacids through the hydrolysis of all peptide bonds (Gotiesman and Maurizi, 1992). Specific proteinases can be used in food processing to improve texture of food, flavor

of Brie or Camembert cheeses, bitterness of food, gelation, digestibility of food, to decrease food allergenicity, for example from soybean, pea, chickpea, lentil, or peanut allergens, and to produce bioactive peptides and aminoacids for clinical or sport diet (Tavano et al. 2018). Even milk proteins can produce allergic reactions for children so properly enzymatically hydrolyzed milk protein could be used as a food supplement in these cases (Osborn et al., 2017). There are known also proteinases that are removing inflammation effect of gluten from wheat, rice, and barley. Hydrolysis of gluten by a mixture of specific proteinases, mainly prolyl endoproteases of some microorganisms, is only one way for gluten-free diet that is preventing auto-immune disorder known as celiac disease (Tavano et al. 2018).

Digestion of food proteins by specific proteinases produces bioactive peptides that can be marketed as nutraceuticals with beneficial actions on digestive, immune, or nervous systems (Tavano et al. 2018). For example, hydrolysis of milk casein by specific proteinases produces peptide with opiate-like effect (Silva and Malcata, 2005; Park and Nam, 2015; Chai et al., 2020).

Functions of proteases in food processing can be extended if the enzymes of microbes-extremophiles will be available. For example, the enzymes of thermophilic *Bacillus stearothermophilus* and can be used at processing temperature 70–80 °C, (Kumar et al., 2019), while enzymes of psychrophilic bacteria are active at 0–4 °C (Yadav et al., 2017; Kour et al., 2019) and can be used to hydrolyze fish, pork, and shrimp meat at 0 °C.

There are many commercial proteases for food industry: Alcalase, a mixture of alkaline proteases, Flavourzyme, containing a mixture of alkaline and neutral proteases, Thermolysin, a thermostable proteinase, but their spectrum is not sufficient for diverse possible applications in food processing industry (Tavano et al. 2018).

Transglutaminases are family of enzymes crosslinking glutamine of one protein molecule and lysine of another protein molecule by the formation of amid (isopeptide) bond and finally resulting in protein polymerization (Rachel and Pelletier, 2013). This ability of transglutaminases for crosslinking of protein molecules, especially collagen that was denaturated at a high temperature, is used in food industry for the meat hydrogels production and to alter the texture of meat (Savoca et al., 2018; Duarte et al., 2020). There are producing affordable microbial transglutaminase for the food industry (Wand et al., 2018).

Transglutaminases are used at present in the cheese manufacturing, meat processing, in the production of edible films from milk protein, and there are wide opportunities to use these enzymes to improve the firmness, viscosity, elasticity, and water-holding capacity of food products. For example, transglutaminase improves the quality of flour and the texture of bread or pasta, forms a texture of the minced meat, forms from gelatin low calorie food with good texture and elasticity, increases hardness of fish paste (Kieliszek and Misiewicz, 2014; Duarte et al., 2020). However, application of transglutaminase could be also a way to produce a false food from the low-quality raw materials or even from the food-processing wastes.

Use of phytases for food processing is due to the role of phytate, a dihydrogenphosphate ester of inositol, as a storage of phosphate in the major food staff such as cereals and legumes. Phosphate of phytate in this food binds calcium, iron, zinc, and other essential dietary minerals. Phytase removes phosphate from phytate thus preventing mineral starvation. Therefore, it is used in human nutrition and food processing to increase bioavailability of minerals (Herrmann et al., 2019; Handa et al., 2020). Industrially produced bacterial (Kumar et al., 2017) or fungal (Jatuwong et al., 2020) phytases are essential feed and food additives. It is especially important for vegetarian food because phytate phosphorus is not available for human (Jatuwong et al., 2020). However, applications of phytase for the food enhancement in Ukraine are still rare.

Microbial  $\beta$ -galactosidase is used for hydrolysis of lactose in milk because of lactose intolerance in the part of human population. This enzyme is also used for the production of lactose-based sweeteners from the effluents of cheese production. There are known also thermostable or psychrophilic  $\beta$ -galactosidase for the treatment of hot or cold milk (Xavier et al., 2018). Enzyme  $\alpha$ -galactosidase is used in food industry to hydrolyze galactooligosaccharides such as raffinose, melibiose, stachyose, galactomannans and galacto-glucomannans in soymilk and before sugar crystallization process (Bhatia et al., 2020). Bacterial and fungal amylases are often used in food processing for hydrolysis of starch in alcohol fermentation, juice production, bakery. Pectinases are used mainly in wine and juice production to increase yield and quality of juices (Tapre and Jain, 2014; Habrylo et al., 2018; Sudeep et al., 2020).

The wide and increasing range of food processing applications of enzymes require the search of new enzymes and their producers. So, the trend of enzymes application in food processing will remain as actual one in 2021–2030.

### **Use of alive microorganisms for food processing**

Food processing technologies with applications of alive microorganisms for the food and beverages fermentation originated from about 14000 years ago (Marco et al., 2021). All these fermentation technologies like beer, wine, cheese, pickled vegetables, fish and soybean sources production are existing and used at present, but they are enhancing with application of pure and starter cultures of microorganisms, probiotic strains and strains producing antimicrobial metabolites and peptides (Camargo et al., 2018). Microorganisms make different tastes during food fermentation (Tavano et al. 2018), form food preservatives, and produce bioactive peptides with numerous health effects such as antihypertensive, antioxidant, antimicrobial, opiate-like, anti-inflammatory, anticancer/antiproliferative, antithrombotic, hypolipidemic, hypocholesterolemic, etc. properties that can be used in the production of functional food and nutraceuticals (Chai et al., 2020).

Use of probiotics that are selected alive bacteria or yeasts that are used in food or as medical composition (Arevalo-Villena and Briones-Perez, 2017; Marco et al., 2021) originated about 30 years ago. The probiotics with immunomodulation properties, modulating gut microbial community, with different positive health effects is a major trend in the functional food with alive microorganisms (Jankovic et al., 2010; Bajaj et al., 2015; Voitenko and Voitenko, 2021). Modern approaches to probiotic functional food are the symbiotic combinations to stimulate the growth of probiotics (Terpou et al., 2019), production of bioactive compounds by probiotics introduced in food products (Chugh and Kamal-Eldin, 2020), addition to food both bacterial probiotics and their prebiotics such as inulin, fructooligosaccharides, galactooligosaccharides to develop functional products with improved texture (Guimaraes et al., 2020), using probiotics for mitigation of genotoxic and carcinogenic acrylamide that is formed during heating of food (Khorshidian et al., 2020), the production of postbiotics that are metabolites with beneficial functions in different human organs, for example production by probiotic lactic acid bacteria of gamma-aminobutyric acid that connected with the prevention of neural disease, diabetes, cancer, immunological disorders, and asthma (Diez-Gutiérrez et al., 2020). New functions of probiotic and food processing technologies including alive microorganisms will be developed in 2021 – 2030.

## Validation of food processing wastes

Food wastes were often used as a soil fertilizer (Stabnikova et al., 2009). However, the modern trend is a validation of green food processing including utilization of wastes for other food, nutraceuticals, or the mushroom cultivation. For example, grape pomace can be used for production of nutraceuticals containing antioxidants and the mushroom cultivation (Sirohi et al., 2020). Whey proteins can be used for production of bioactive peptides with the health benefits in the immune, cardiovascular, nervous and gastrointestinal systems (Dullius et al., 2018). The industrial biowastes such as peels and seeds of vegetables can be used for the production of carotenoids to enhance quality of macaroni (Martins and Ferreira, 2017). Every on-farm plant processing releases enormous quantity of wastes. For example, processing of cocoa beans from which confectionery for US\$47 billion is producing, releases 80% of raw material as a waste which is disposed for soil fertilization giving putrid odors and increasing plant diseases. Meanwhile, the cocoa by-products can be transformed to the food, pharmaceuticals and cosmetics (Vasquez et al., 2019). Chicken feet can be used for enzyme-mediated production of 180–380 kg of food gelatine from 1 ton of dry waste (Mokrejs et al., 2019). Potato-processing wastes can be transformed using biotechnological methods to proteins, lipids, food-processing enzymes, and food organic acids (Javed et al., 2019; Kot et al., 2020).

Spent yeasts from beer production can be used for production of yeast extract containing a lot of edible and biologically active components (Jacob et al., 2019). There are many other examples of food waste validation (Stabnikova et al., 2010), so this trend will be just increased in 2021–2030.

## New food sources

Meat is not environmentally friendly food because of the energy and material losses during the trophic chain from plants to animals and finally to human, and due to release of greenhouse gas emissions to atmosphere from livestock and poultry. However, significant part of population considers meat as the most delicious food. So, new type of food, plant-based meat that is made from the plant protein, is produced at present and the scale will be increased to satisfy the tastes and nutritional quality.

Another environmentally sustainable potential source of food is “single-cell food”, *i.e.* proteins, lipids, carbohydrates, and vitamins of cultivated microscopic algae, yeasts, bacteria, and even cells of plants or animals that can produce protein from carbohydrates by hundred or thousand times faster than animals.

Micro and macroalgae are good sources of food and now biomass of *Spirulina* and *Chlorella* from some producers have GRAS (“Generally Recognized As Safe”) designation. This food industry requires extraction of the healthy bioavailable components of algal biomass for the production of functional food or nutraceuticals (Wells et al., 2017; Caporgno and Mathys, 2018; Junior et al., 2020; Kusmayadi et al., 2021). Many species, especially among psychrophilic algae, contain lipids with polyunsaturated omega-3 fatty acids (Dhanya et al., 2020; Stokes et al., 2020) that can be used in nutraceuticals. Commercial biotechnological applications are known for such microalgae as biomass of *Dunaliella salina* containing up to 3.5% of beta-carotene, *Scenedesmus almeriensis* containing 0.30% of carotenoid lutein, *Chlorella vulgaris* containing 45% of protein, *Nannochloropsis sp.* producing carotenoid astaxanthin and omega-3 fatty acids, and representatives from the genera *Botryococcus*, *Chlamydomonas*, and *Arthrospira* (marketed as *Spirulina*) (Caporgno and Mathys, 2018; Molino et al. 2018; Junior et al., 2020). There are still many problems in



“single-cell food”, for example excessive content of nucleic acids and low digestibility of cell walls, but in every case this direction of new food production will be developed

Edible insects are another unusual source of food (de Carvalho et al., 2020; Van Huis, 2020). The market of the protein food from the edible insects will be increasing with forecast up to US\$4.6 billion in 2027, especially if The European Food Safety Authority will approve the sale of insects: ground mealworms, lesser mealworms, locusts, crickets, and grasshoppers for human consumption, as it is expected by business (Meticulous Research, 2020). However, after admission of the edible insects to the market, there must be developed proper rules to assure consumers of their benefits and safety (Belluco et al., 2017). Entomophagy is not attractive for European and American cultures, so insect food can be consumed there as a nutritional powder addition to the conventional food. For example, biomass of 2000 edible species of insects can be used as a source of iron and zinc in human nutrition (Mwangi et al., 2018).

Notwithstanding the negative public perception, the food from genetically modified organisms (GMO) will be developed further because it can have higher levels of essential and valuable nutrients, and better taste. Moreover, with the new CRISPR method of gene editing it will be possible to create the genetic variants of plants and animals that will be the revolutionary sources of conventional and functional food. However, there must be also created and used the revolutionary methods of molecular-biological control for this new GMO food.

## **Trend 5. Personalization of food processing and distribution**

### **Nutritional needs of the medical, racial, religious, and regional customer groups**

Types of food and dietary habits are tightly connected with culture. To increase consumption of healthy food not only political or technological decisions have to be made but also optimization of the diet and related food production for the specific age, ethnical, medical, racial, religious, or regional group of the customers. Some of this topics are discussed in the above section “Trend 2. Functional food and nutraceuticals”. These differentiations will be more scientifically specified and their production and sales should be increased in 2021 – 2030.

### **Computerization of the personalized food production and consumption**

Nutrition-related mobile applications became of common tool of the human nutrition (Flaherty et al., 2018; Ahmad et al., 2020). They are calculating right now mainly calories of the food to avoid obesity. There were screened 628 dietary guidance in China, and 75% of them were focused on energy intake and only 23% advised dietary structure. Many applications were developed for health management and some of them have social communication tools (Li et al., 2019). So, it is possible that very soon we will select the food in the supermarket that were optimized for the personal diet using mobile tool or computerized order of the food from home. Food production and retail will be totally changed due to digital short-term and long-term personalization of the food consumption.

### **Consumer acceptance of a new food**

However, the problem of new food technologies is consumer acceptance of a new food or computerized optimization of the diet (Priyadarshini et al., 2019). To ensure commercial adoption of new food products (Santeramo et al., 2018), the consumer acceptance of new food technology and food product is the most important factor (Priyadarshini et al., 2019; Meijer et al., 2021). The consumers, usually, are hesitant to accept new food (“food neophobia”) even the novel food technologies are important for the health diet, food safety and sustainability (Siegrist and Hartmann, 2020). Consumers often rely in their evaluation the naturalness of new food product of food technology due to lack of the food engineering and technology knowledge (Siegrist and Hartmann, 2020). So, the trend is the development of new food and new food technology accounting all aspects of consumer acceptance: from agriculture and farming to processing, storage and distribution of a new food, its ecological and environmental sustainability aspects, cultural and religious factors, functions in healthy or medical diet, plus some personal attractions of new food.

### **3D printing of food**

3D printing of food could be considered as one approach in the personalization of nutrition, customized food designs, and simplification of food supply chains. It could be more expensive than conventional food products but it will satisfy personal taste, aroma, texture, diet components, a view of food, an artistic impression from the food, and a way of personal food consumption (Nachal et al., 2019). So, it is used as military and space food, and specific diet food (Liu et al., 2017).

Important and not solved yet technological points are the accuracy of printing of colorful and multi-flavor food; development of printable food materials, post-processing of food 3-D print such as cooking, drying, fast cooling technology (Liu et al., 2017; He et al., 2020). Plant-based 3-D printed food can be made by the ink of cell suspension with alginate that is cured with calcium ions after printing to form a rigid gel (Park et al., 2020). 3-D printing food based on protein, starch and fiber-rich materials showing uniformity of extrusion as well as the precision and stability of the printed pattern. The best printing precision, shape stability after printing and after post-printing oven drying shown a semi-skimmed milk powder-based paste (Lille et al., 2018). However, consumers attitude toward 3D-printed food is not clear because it is not clear yet safety and benefits of 3D-printed food (Brunner et al., 2018). This direction of food technology is just starting.

Commercial food became so diverse in 2021–2030 that the specific nutritional computer programs with the comprehensive information on this food as well as personal diet requirements will be used for the optimization of the production and delivery of the personal-specified food.

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