Emerging Trends in Sustainable Food Processing Industry

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Abstract. Food industry undergoes a dynamic innovation and digital transformation in ensuring food security and sustainability in the rapidly growing global population. In this sense, it is necessary to evaluate the technological trends and advances that will change the food processing industry. It is crucial to evaluate the influence of food processing technology to produce a nutritious and easy-to-handle food as well as its supply chain. This is particularly important to meet certain standards and customers’ demands, and this paper presents halal requirements in the supply chain. Digital technology can also help the food industry in the new era to make it easier for consumers to get food more easily, quickly, and with more options without having to go to the food premises. Therefore, this paper discusses on thermal and non-thermal food processing trends in the context of preparation of ready-to-eat food, three-dimensional (3D) food printing, and utilisation of digital technology in food industry and services.

Keywords: Nutritious; Food; Processing; Technology; Halal; Thermal; Non-Thermal

1. Introduction

Currently, focusing on consumer needs is key to the success of the food industry and services. This often involves new technology in food processing to produce novel products, application of digital technology in food services, and others. It is crucial to evaluate the influence of these sustainable technologies for future food industry consolidation. A range of new food processing technologies have been investigated and developed to modify or replace traditional food processing techniques for better food quality and to manufacture more consumer preference-oriented foods [1]. The focus has been on quality over the last decade, enhancing the process efficiency, safety, productivity, and stability of food products in a healthier way [2]. The nutritional quality of food is influenced by factors such as quality of raw material, transportation, processing techniques, packaging, storage, and the whole food chain (farm-to-plate) [3,4]. Nowadays, an impressive displacement process is taking place worldwide on ready-to-eat foods, which substitutes conventional foods focused on fresh meals. Ready-to-eat food is categorised as a food product which without prior preparation or cooking, pre-cooked, pre-cleaned, often packed and ready for consumption [5]. Therefore, a vast food processing technology is important in the production of ready-to-eat food that is safe for consumption.

Besides that, three-dimensional (3D) food printing has gained new attention from manufacturers in its aim to produce more food products. 3D food printing is the method of producing food products using a variety of additive manufacturing techniques. 3D food printing can produce printed food that can be customised according to customers’ needs [6]. This approach will bring significant changes in
the manufacture and supply of food demanded by the population. According to Demartini et al. [7], it can be argued that over several years, the subject of digitalisation in the food sector had begun to be extensively studied with keywords associated with “Food” and “Factory of the Future”. In addition, the latest developments in digitalisation that define the food industry may be recognised as “Robotics”, “Sustainability”, and “Internet of Things”. These technologies have powerfully affected the consumer behaviour towards their daily needs such as food buying and groceries, among others. The use of digital technology can be the best solutions to order food from food premises, individual seller, and etc., particularly for people with busy lifestyles and those facing crisis.

Therefore, this paper reviews in detail the conditions of the food industry and analyses specifically the application of emerging technologies in food processing trends in the context of preparation ready-to-eat food, 3D food printing, and utilisation of digital technology in food industry and services.

2. Concept of farm-to-plate
Farm-to-plate, also known as farm-to-table, literally means the processing of raw materials or sources from the primary sector, such as farm and sea, into food in food industries in order to meet customer demand. Further preparation or slight processing of the food then takes place before it is served for consumption. The production, manufacturing, distribution, retail, and consumer are steps of supply chain for food system [8]. Presently, more people throughout the world are deemed to have become more concerned about their food consumption and its sources.

Farm-to-table is also about the transportation of food from the farm directly to consumer table, either to individual, family, or to the restaurant. In terms of cleanliness, religious protection and healthcare, plants, and animals in the farm need to have proper treatment and more requirements, as there are many religions in this world that have its own reason and requirement [8]. For example, Muslim consumers have a major concern for the integrity and legitimacy of the halal status from farm-to-table. Halal certification may be used to provide those food items with halal status directly. It is only possible to receive the halal logo if all requirements dictated by Islamic values have been thoroughly followed. Consequently, this halal logo will boost Muslim consumers’ awareness and trust in the availability of food processed under religious supervision [8]. Muslim consumers deem it vital that the food consumed is halal and free from tainted or polluted elements [9].

There are also some halal applications (apps) in the commercial online play store to help Muslim consumers in ensuring the halal status of food. Many apps have search features, where users can search for desired items or stores and a list will appear. Then, details such as the name of company, business, and halal status data will be shown. An app called myJakim was developed by the Department of Islamic Development Malaysia (JAKIM) in order to offer details that consumers seek [10]. Furthermore, “Verify Halal”, “Halal Jakim”, “Halal Jakim Barcode Scanner”, and “Halal Check E-number and E-codes” are apps that can be found in the play store. These apps allow consumers to have a quick access to a list of halal certified foods and barcode scanning features [10].

3. Food processing technology
Several factors have driven the development of food processing technology, including consumer demands, which have inevitably guided the emerging development in food production, preservation, and control. Factors that have shaped the lifestyle and eating patterns of consumers include history, demographics, socioeconomics, political, and environmental factors. The new trends in food processing, including new advances in techniques and methodologies for the production, storages and monitoring of food, reflect these influential factors. Consumer demand is directed towards new foods that are convenient and easy to sustain. Consumers are becoming more conscious of the need for safer products, increasing the need for non-synthetic chemical preservatives for fresh or minimally processed food [11]. Over the past decade, the focus has been on quality, to improve the process efficiency, safety, competitiveness, and stability of food products in a healthier way [12].

Nowadays, an impressive displacement process is transpiring globally with regard to ready-to-eat foods, which substitute conventional foods that focus on fresh meals. Additionally, ready-to-eat food
is a category of food products without prior preparation or cooking, that is without the need to be pre-cooked, pre-cleaned, and is often packed and ready for consumption [5]. These foods are also processed and can be eaten without further care such as through heating [13].

However, the safety of ready-to-eat food depends on the utilisation of suitable materials, processing operation, storage temperature, packaging, shelf-life, and cross-contamination [14]. Although ready-to-eat food is designed for its time-saving feature, with minimal time for preparation, improper handling of these items can lead to foodborne diseases. *Salmonella*, *Staphylococcus aureus*, and *Escherichia coli* are pathogens often associated foodborne illnesses [13]. Among these pathogens, *Listeria monocytogenes* is the most common pathogen in ready-to-eat refrigerated foods. It can survive in temperatures between 1°C and 45°C, but optimally at a range of 30°C to 37°C. A wide variety of food items include pates, soft cheeses, milk, ice cream, coleslaw, ready-to-eat meat and poultry, smoked and lightly processed seafood products, are isolated from *Listeria monocytogenes* [5]. During transportation, cross-contamination can occur if there is no clear segregation, particularly if both halal and non-halal products have been used in the same container transport. One fundamental solution is that suppliers or manufacturers are required to use the company’s own dedicated transport [15]. This requires separation across the entire supply chain of halal ingredients or finished products from non-halal foods or products, including pork-related or alcoholic products, for maintaining the halal integrity assurance (HIA) [16].

Furthermore, the services of halal transportation will be strengthened by introducing halal compliance and minimising the contamination risks. Services and operations provided by the halal transport company must comply with the specifications and standards of Sharia [17]. In addition, the key differences between operation of halal logistics and the conventional operation of logistics are the segregation method of food handling with non-halal and dangerous elements [18]. In Malaysia, the online delivery platforms offer a greater option for halal consumer products [19].

Besides the production of ready-to-eat food products, 3D food printing is one of the latest methods of producing food products using a variety of additive manufacturing techniques. Food grade syringes commonly contain the printing material, which is then deposited layer by layer through a food grade nozzle. The most advanced 3D food printers have preloaded recipes on board and allow users to design their food remotely on their computers, phones, or other Internet of Things (IoT) unit. The ability of 3D printed food that can be customised according to user needs makes it beneficial in many fields, such as medicine, and may also represent a hope for the world hunger crisis in the future [6]. Details of ready-to-eat food production using thermal, non-thermal, and a combination of these processing techniques, as well as 3D food printing, are explained below.

### 3.1 Thermal Processing

Figure 1 shows the thermal processing techniques, such as pasteurisation, retort, microwave, and high-temperature and short-time (HTST). The process can eliminate pathogens such as *Listeria monocytogenes*, *Escherichia coli*, and *Salmonella*. The effectiveness of in-package pasteurisation in the inactivation of vegetative pathogens depends on the temperature and time of pasteurisation applied to the food product. The packages need to immerse in a water bath that is held at 90.6°C, 93.3°C, or 96.1°C and heated between 2 and 10 min [5].

On the other hand, retort processing is intended to destroy microorganisms in ready-to-eat products by applying intense heat conditions at 121.1°C in order to increase the shelf stability of the product [20]. Retort pouch has been commonly known as an alternative to metal cans for the development of thermally processed shelf-stable foods. One of the biggest advantages of retorting ready-meal packages is that both the food and the package are thermally processed together, making it possible to commercially sterile the filled packages [21]. However, food can lose its nutritional content and quality due to exposure to heat and moisture [22].

Moreover, a microwave heating is a process of heat transfer and several ranges of electromagnetic microwave radiation (1 to 100 GHz). Due to the electric and magnetic fields that produce heat, any food that is exposed to the microwave will be heated [23]. It is used for heating and thawing food in household, since it is easy and convenient. Besides that, it is used in food industry to dry food, bake
bread and biscuits, prepare and cook food, bleach vegetables, defrost food, and pasteurise food products [23,24,25]. However, some of the microwave heating systems are difficult to control and can cause a non-uniform heat distribution, and prolong heating can affect nutrient losses to the food [26].

**Figure 1.** Thermal, non-thermal, and a combination of these processing techniques.

Utilisation of high-temperature and short time (HTST) extrusion cooking in the preparation of a ready-to-eat product can enhance the nutritional quality of sorghum-based foods. Extrusion systems enable the replacement of conventional methods that are difficult and impossible to handle to treat extremely viscous materials. This advantage can save the costs of labour, floor space, and energy, thus increasing efficiency [27].

Combination of thermal processing methods in food processing is also developed to extend the shelf life and kill pathogens effectively. These methods consist of microwave-assisted pasteurisation (MAP) and microwave-assisted ultraviolet sterilisation (MWUV). MAP is a combination method of pasteurisation and microwave, in which it adopts the application of hot water from pasteurisation and electromagnetic energy from microwave. This method heats food products with uniform heat distribution that is absorbed through the food components. There are four processes of MAP, which are preheating, microwave heating, holding, and cooling, all of which give better food quality and reduce the processing time [28,29]. In conventional microwave, 2,450 MHz is one example of a
multiple-mode microwave heating cavity model. It was reported that the MAP uses a longer microwave wavelength of 915 MHz, which permits single-mode cavities to handle a large range of food packages [30]. Utilisation of MAP is to minimise reduction in quality and to extend the shelf life by reducing the bacterial or viral pathogen in the food, as compared to conventional microwave [31].

In addition, an MWUV is the combination of both microwave and UV, which has greater efficacy in reducing microbial count with maintaining the quality of milk. On top of that, MWUV indicated less coliform bacteria and sterilised the milk without degrading its natural properties [32].

3.2 Non-thermal processing
The development of spoilage and pathogens for food items during shelf-life can be controlled by non-thermal process such as ultrasound, ultraviolet (UV), cold plasma treatment, and high-pressure processing (HPP) (Figure 1). Ultrasound is useful and can be combined with thermal processes, therefore, maximising the energy consumption by accelerating the sterilisation efficiency [33]. It is applied for analysis and quality control in food processing and can be classified into low and high energy from its given frequency range. Apart from its usefulness in processing and preservation processes, ultrasound is used to extract bioactive compound in plants or food [34,35]. However, it is recommended to be combined with other decontaminating treatments to obtain better effectiveness [33,36,37,38]. The composition and food texture can also be undesirably altered. Certain food properties, including taste, colour, or nutritional value, are negatively modified [39].

Furthermore, UV radiation with wavelengths in the range of 220–280 nm, particularly at 254 nm, is well known to be able to inhibit the multiplication of bacteria by inducing the DNA thymine dimers formation [40]. Moreover, UV light is useful for decontaminating solid foods, especially packaged products. This technology has been used in sterilisation and microbial load reduction in food processing equipment, food surfaces, or packaging materials because of its low penetration level. In addition, this technique with UV light is used in the pasteurisation process of fruit juices as an alternative method [39]. However, sample heating is the most critical limiting factor for pulsed light. Depending on the processing parameters utilised, it may facilitate lipid oxidation, such as the exposure period and distance of food from the pulsed UV light source [41,42]. Furthermore, it is important to improve the dose response behaviour of food pathogens in viscous liquid food. In order to predict UV disinfection rates on food surfaces, more kinetic inactivation data is needed for pathogen and spoilage microorganisms [39].

Besides that, cold plasma treatment is considered a modern non-thermal technology, as it uses lower energy consumption and temperature demand in food processing for microbial inactivation and decontamination of food products [43,44]. Cold plasma treatment is a fast technology that does not leave harmful traces or exhaust gases after processing. However, aspects of the nutritional content, colour, chemical changes, texture, and general consistency of the food must be considered. There is no commercial instrument available for sanitising and disinfecting food products. Furthermore, apart from the industry, it is adopted by different research agencies and universities [39].

In addition, the most successfully commercialised non-thermal processing technology is high pressure processing (HPP) [45]. It is a minimal thermal technology applied to food products (100–1000 MPa), which is mostly conducted at room temperature [46]. This technology has been mainly targeted to replace thermal processing technology. This technology guarantees the safety of food from microorganism and enables the processed food to preserve the natural flavours and nutritional value of original food content. Therefore, HPP technology is known as a minimal processing technique that guarantees both food safety and taste [47]. However, this technology has several limitations, including the survival of many microbes and food enzyme activity, limited packaging option, and is expensive [39].

Pressure-assisted thermal sterilisation (PATS) is a technology that improves the use of HPP by taking advantage of the self-generated heat during compression. In practical terms, HPP alone is unable to sterilise foods due to equipment restrictions in terms of cost and technical obstacles. The smart combination of HPP and thermal energy makes it possible to obtain very healthy foods of superior quality, compared to traditional thermal treatments [48]. As a method that uses low maximum
temperature and is of short operation, PATS requires the utilise of modest temperatures of initial chamber between 60°C and 90°C, in which the in-process temperatures can exceed anywhere between 90°C and 130°C by internal compression heating at pressure of 600 MPa or higher [49]. Moreover, the method offers a high-temperature–short-time processing method, as both pressure and compression heat contribute to the lethality of the process [48]. The isostatic pressure at room temperature ranging from 100 to 1000 MPa is used in HPP in order to inactivate pathogenic and spoilage microorganisms to preserve the quality of food products [50].

3.3 3D food printing

Current 3D printing techniques that are available in food sector generally have four types, which are extrusion-based printing, selective laser sintering printing, binder jetting, and inkjet printing [51]. Extrusion-based printing creates a food model by extruding food with continuous pressure through a nozzle. This method is close to the conventional fused deposition modelling (FDM). However, with low viscosity, the starting material for extrusion-based printing may be both solid and paste (soft), whereas wire is the starting material for FDM. However, both solid and paste (soft) with low viscosity may be the starting material of extrusion-based printing, whereas FDM's starting material is wire. Dough meat paste and cheese are an example of food processed using this technique [52]. Besides that, selective laser sintering is a technique that incorporates a power laser into a 3D structure to selectively fuse powder particles layer by layer together. On the surface of each layer, the laser scans cross-sections and selectively fuses the powder. The powder bed is lowered and a new layer of powder is covered on top after scanning every cross-section. This process is repeated until a suitable structure is obtained [51].

Binder jetting creates a model by using a binder to selectively bond the powder layers. Tiny droplets of binder with a diameter of less than 100 μm are successively deposited on the powder bed surface in this process, which is a drop-on-demand print head based on the scanning pattern of the ratter [52]. The properties of the powdered material and binder are vital to the efficient in the binder jetting process. The binder must have sufficient viscosity, surface tension, ink density, and acceptable properties in order to prevent nozzle from spreading [51]. The inkjet printing dispenses a material stream of droplets from a thermal head to certain regions for creating the surface filling or decorating on food surfaces, such as cookie, cake, and pizza [52]. There are two types of inkjet printing methods, which are continuous jet printing and drop-on-demand printing. In a continuous jet printer, ink is ejected continuously through a piezoelectric crystal vibrating at a constant frequency. A desired flow ability of the ink can be charged by the addition of some conductive agents. In a drop-on-demand printer, ink is ejected out from heads under pressure exerted by a valve. Generally, the printing rates of drop-on-demand systems are slower than that of continuous jet systems, but the resolution and precision of produced images are higher [51].

3D food printing can be applied in professional, industrial, and personal use cases. For example, 3D food printing is usually used for personal nutrition for elderly in the production of nutritious food with tailored dietary requirements for the needs of an individual [53]. In this case, the amount of protein, sugar, vitamins, and minerals can be controlled in the production of 3D printed food [54]. 3D printed foods can also provide soft and aesthetically pleasing food that helps the elderly to increase and meet their nutritional requirements. While the 3D printing technology in Malaysia is clearly in its infancy stage, it is anticipated that this technology will grow and become one of the major innovations in the country [55]. Currently, there is an increasing demand for the production of customised food for special dietary requirements, such as for pregnant woman, children, athletes, and patients, all of whom need a different amount of nutrients, by reducing the quantity of excessive ingredients and improving the healthy ingredient in the food [56]. 3D printing technology that is eco-friendly, low in cost, and good in quality control is a high-energy efficiency technology for food production. Furthermore, 3D food printing can be beneficial, as it enables new food customisation process and the adaptation to individual tastes and needs [57]. 3D food printing is also used in the production of chocolate, gum, and other sugar-based items due to high demand and consumption of these products. The market size of
global confectionery is expected to reach $232,085 million by 2022, which is supported by a CAGR of 3.4% during the forecast period of year 2016 to 2022 [58].

However, 3D food printing has several disadvantages, as it is still new in the food industry and requires more in-depth research in order to obtain the best outcomes. 3D printed food is limited by the physical characteristics of the materials, in which the food materials are usually much softer and fragile [56]. 3D food printers also have difficulties to develop multiple extruder and edible ink capabilities to produce a complete dish. In addition, Shahrubudin et al. [55] reported that the 3D food printing process is more time consuming and labour intensive, as most foods require some preparation in order to transform them into an ink that is capable of being extruded. Some food design requires successive layers of ingredient to cool; consequently, this delays the production of the next new batch.

4. Digital technology in food services

Online food ordering is the method of ordering food from a website or from another programme. The product may be either prepared food (e.g., direct from home-kitchen, restaurant, or other sources) or food that has not been specially prepared for direct consumption (e.g., farm-to-garden vegetables, frozen meat, etc.). An online food ordering system can be described as a software that enables restaurant businesses to accept and manage orders placed over the internet. Online ordering systems typically consist of two main components. The first component is a website or smartphone applications is used by customers to view restaurant dishes and place an online order. Customers can then proceed with online payments via credit card, bank transfer, and debit card through the website or in cash at the food premises during pick-up. The second component is the administrative management interface for restaurants to accept and handle customer orders [59]. It is expected that online ordering technique to increase over the years.

Food can also be ordered through social media, where the consumer contacts the seller, and the seller takes orders and customer information themselves without involving a third-party. This method is easy, fast, and time- and energy-saving [61]. In most cases, food riders or drivers will deliver the ordered food directly to the customer. In Malaysia, there are many food delivery companies available. Riders that deliver food usually need to own a motorcycle with a valid driving license. They will use a smartphone with a data plan to update on all their progress deliveries to vendors and customers alike.

Therefore, there are a few advantages on online technology in food services, such as easy, quick ordering, and minimal contact without having to go to food premises. This technology is very useful for the current situation of Covid-19 pandemic, which prevents or minimises contact transactions between food premises and customers to prevent the spreading of virus.

5. Conclusion

Food processing is important, as it affects food preservation in extending the shelf life of food by discriminating pathogens so as to provide safe food. The preparation food should also consider customer requirements, such as requirement of halal food for Muslim consumers. Apart from that, modern and novel non-destructive methods are practical for maintaining food nutrient and quality. Additionally, the combination of several methods in food processing may produce products with an optimal result. More researches related to ready-to-eat food and 3D printed food need to be focused on to improve the quality and safety of the products. Therefore, applications of online food delivery services are undergoing rapid changes, as new online platforms race to capture markets and customers. There has been significant investment in technology companies aiming to disrupt the market with new ordering and delivery methods. Thus, the whole supply chain in the food processing industry is important in ensuring food security and sustainability through a global demand.

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