Current Trends in Intelligent Control Neural Networks for Thermal Processing (Foods): Systematic Literature Review

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Abstract— **Thermal processing is a technique for sterilizing foods through heating at high temperatures. Thermal processing plays a significant role in preserving foods economically, efficiently, reliably, and safely. Control in thermal processing of foods is necessary to avoid any decrease in food quality, i.e., color change, reduced content, sensory quality, and nutrition. Artificial Neural Network (ANN) has been developed as a computing method in research and developments on thermal processing methods to discover one suitable for food processing without damaging food quality. To this date, ANN has been used in food industries for modeling many processes. The paper aims to identify the latest trend in intelligent neural network control for the thermal processing of foods. The paper conducted a systematic literature review with five research questions using Preferred Reporting Items for Systematic Review (PRISMA). According to screening results and article selection, 240 potential articles have fulfilled the inclusion criteria. Then, each article was explored to identify the advantage and the advance of intelligent network control in thermal food processing. It can be concluded that the technology in information and computations of food processing has rapidly developed and advanced through the utilization of a combination of ANN with fuzzy logic and/or genetic algorithms.**

Keywords*— *Artificial intelligence; Neural network; Artificial Neural network; Thermal processing; Food processing

I. Introduction

Thermal processing has been used in many food industries. It aims to reduce and destroy microbes or enzymes contained in foods. Thermal processing is a food sterilization technique that uses heat at high temperatures. The time needed for thermal processing depends on foods' microbial or enzyme activities [1]. Thermal processing in food industries can be done using pasteurization, heat sterilization, and blanching. The selection of the technique used in thermal processing depends on the objective and the variety of the resulting food products. Foods made of plants and animals contain humidity, protein, fat, and organic substances. Food deterioration occurs due to microbial activity, chemical substances, or physical actions. Consequently, its nutritional value, color, texture, and eligibility may change, making the food vulnerable to decomposition [2], foods need to be preserved so that the food quality will last longer. Thermal processing plays a role in food preservation that is economical, efficient, reliable, and safe. Food preservation is defined as a process or technique carried out in order to maintain internal and external factors that may cause food decomposition [3], [4], [5].

In thermal processing, control is necessary to avoid any decrease in food quality, such as changes in food color, decreased food content, sensory quality, and nutrition. Excessive thermal processing negatively impacts food qualities, especially foods' nutrition and sensory quality [6], [7]. Moreover, overheating can reduce food quality, is considered energy waste, and can damage factory capacity. The compatibility of time and temperature during the thermal processing must be controlled to destroy microbes that role in food decomposition and the target microbes [8], [9]. Thermal processing in foods is best to be carried out within 12 log cycles from the microbes' initial growth cycle or at least at 121.1°C for 3 min [10]. Some calculations in thermal processing are necessary to be done, including the processing time. The processing time at a specific retort temperature must be carefully calculated to reach a safe level of microbial activity inactivation, ensuring public safety and health. For these objectives, the accuracy in the calculation method is essential for the development of food science and its professional technical practitioners [11], [12], [13].

Research on thermal processing continues to develop. A new methodology was studied in [14] for thermostatic room temperature measurement used in food-meat industries. A study in [15] showed that an improved psychrometer was developed to solve practical problems in measuring the relative humidity of drying environments, which are challenging for meat production. Besides, research on the boiling point and specific heat of meat extract was done [16]. Meanwhile, the effect of thermal processing on nutrition, anti-nutritional and antioxidant properties of Tetracarpidium conophorum (African walnut) was studied in [17]. Primarily, research on the thermal processing of foods continues to be developed to discover thermal processing methods suitable for food processing without damaging the food qualities such as food color, food content, sensory quality, and nutrition [18], [19]. Research developments on sterilization systems and heating equipment, such as microwave heating and ohmic heating, continued to be conducted. Along with technological advances, especially in artificial intelligence, Neural Network has currently developed as a computing method in food thermal processing.

Neural Network is a parallel information processing system consisting of a number of neurons (nodes or units), which are arranged in layers and connected by links. Neural Network mimics the highly interconnected structure of the human brain and nerves [13], [20]. According to [21], Neural Network is a computational method that builds multiple processing units based on interconnected connections. A network consists of an arbitrary number of cells, nodes, units, or neurons that connect sets of inputs with outputs. Neural Network is part of a computer system that mimics how the human brain analyzes and processes data. The Neural Network requires all the complexity and daily-based algorithm analysis and calculations on how the human brain evaluates knowledge [22], [23], [24], [25].

In many applications of Neural Network, Neural Network has some advantages compared to other similar computation or optimization methods: 1) In some cases, the solution resulting from other algorithms can be costly or maybe is inexistent in reality; Neural Network works by mimicking how the human brain analyzes a problem so this issue can be disregarded, 2) Neural Network learns using samples, so a complex programming code that accentuates every detailed aspect is unnecessary, (3) Neural Network has good accuracy [26], [27]. Moreover, it has a broad scope in developing artificial intelligence and future technology developments. Therefore, an Artificial Neural Network (ANN), which is a part of soft computing methods, can be developed and applied in many areas of food processing [28], [29], [30], [31], [32]. ANN has been used in food industries for many process modeling, such as estimation model of food antioxidant property, modeling food drying process, prediction model of products indicators (water content, crumb temperature, food color, relative volume) using several inputs (drying parameter, temperature of jet, speed of jet, and grilling time) [33].

Based on the aforementioned introduction, the paper was written with the aim of identifying current trends in intelligent neural network control for the thermal processing of foods.

II. METHOD

The research applied a systematic literature review method using the Preferred Reporting Items for Systematic Review (PRISMA). The research was done systematically using proper methodological steps. Comprehensive and balanced data was provided to synthesize relevant study results. Steps in the systematic literature review method used in the paper include: formulating the research problems, collecting literature, screening and selecting relevant articles, then analyzing the data, synthesizing the qualitative results, and writing the research report [34]. Procedures used in the systematic literature review are: writing the research background and objectives, formulating the research problems, collecting the literature, selecting the articles, extracting the articles, assessing the original study quality, and data synthesis [35].

III. RESULTS

A systematic literature review is one of the research methods that aims to identify, analyze, and evaluate all the results of previous studies. The research results that have been obtained follow the methodological steps.

Research questions formulation

The formulated research questions related to the research theme are listed in Table 1.

TABLE I. RESEARCH QUESTIONS USED IN THE SYSTEMATIC LITERATURE REVIEW

Code	Research questions	Background motives
RQ1	What are the developments of thermal processing methods in food processing?	Identifying articles related to thermal processing in food processing
RQ2	How is the temperature controlled in food thermal processing?	Identifying articles related to temperature control in thermal processing of foods
RQ3	What are the developments of intelligent temperature control using neural networks in food processing?	Identifying articles related to the development of temperature control using neural networks in food processing
RQ4	What are the developments of intelligent neural network control in food processing?	Identifying articles related to the development of intelligent neural network control in food processing
RQ5	What are the developments of neural network control methods in food processing?	Identifying articles related to the development of neural network control in food processing

Collecting related literature

Data collection was conducted to relevant articles using keywords: artificial intelligence, neural network, thermal process, temperature control, neural network control, and food. Articles were collected from various databases, such as Scopus, Web of Science, and Researchgate. Only articles in English were included in the data collection process.

Articles' screening and selection

Screening and selection of collected articles were conducted to get articles with the highest relevancy to research questions. Inclusion and exclusion criteria determined previously by researchers were applied as a strategy in the screening and selection process. The inclusion criteria used for the research are: articles written fully in English, fully published in one of the international journals in 2000-2022, indexed in a database, and related to topics in intelligent neural network control for food thermal processing. Meanwhile, the exclusion criteria used in the research can be seen in Fig. 1, along with the results of each criteria's screening and selection process.

The collected samples were then analyzed to obtain relevant information regarding the themes and research questions. The extracted articles were then re-analyzed and synthesized to observe, describe, and classify the obtained data. Then, the data obtained was used to collect knowledge and information on the defined theme and were meta-synthesized. A new concept can be obtained through meta-analysis to alter qualitative studies into new knowledge, and scientific knowledge can be disseminated.

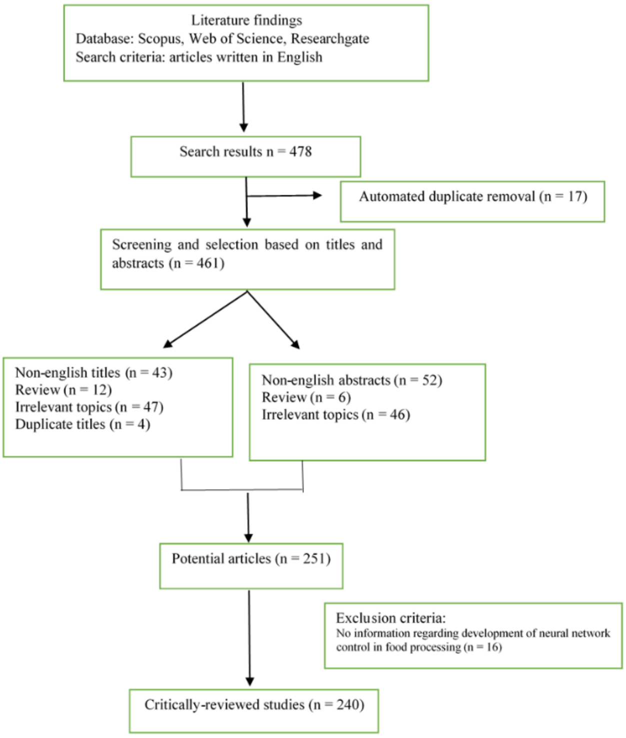

Fig. 1. Flow diagram of a systematic literature review conducted in PRISMA

Data extraction, original study quality evaluation, and synthesis

Data extraction aims to collect data in order to answer the research questions that have been set. The research quality evaluation plays a role in determining the interpretation of the synthesis of the findings and forming the conclusions. Data synthesis aims to collect evidence from selected research to answer research questions.

Discussions

The search for articles in three databases resulted in 478 articles. After conducting the screening and selection process, 240 potential articles that fulfilled the inclusion and exclusion criteria were obtained. The theme "current trends in intelligent neural network control for thermal processing (foods)" was set as a new statement theme in the meta-analysis of the 240 articles. The defined theme discusses thermal processing, neural network, intelligent neural network control, and intelligent neural network control for thermal processing, along with its various developments.

Food thermal processing was conducted to reduce or destroy microbial and enzyme activities. Besides, thermal processing can also be conducted to create physical or chemical changes to fulfill a certain desired quality. For example, in starch gelatinization and protein denaturation, foods can be safely consumed due to the foods' physical or chemical changes. Thermal processing can also be done by pasteurization and sterilization [36], [37], [38].

Some heat processing methods that are used in food industries can be categorized as mild processes (blanching and pasteurization) and more severe processes canning, baking, roasting, and drying) [10]. According to [39], thermal processing can be classified based on the intensity of the heat treatment, which are pasteurization (ranging at 70-80oC), sterilization (ranging at 110-120oC), and ultra-high temperature care (ranging at 140-160oC).

Pasteurization is a heat treatment where foods are heated at temperatures lower than 100oC. The method is generally used to preserve liquid and semi-solid foods. In foods with low acidity (pH>4,5), such as milk, pasteurization is used to minimize pathogenic microorganisms and extend storage life from several days to a week. Whereas, in acidic foods (pH <4,5), such as fruit juice, storage life is extended to several weeks by destroying microorganisms that cause decomposition and inactivating enzymes [40].

Heat sterilization is an operation of heating foods at a sufficiently high temperature for a sufficiently long time to destroy vegetative microbial cells and spores, and suppress enzyme activities [41], [42]. Consequently, packaged foods that have been sterilized have more than 6 months of storage life at room temperature. Foods are also cooked and need minimum heat prior to consumption to improve practicability. However, overheating during sterilization in the packaging (in cans or bottles) may result in substantial changes in foods' nutritional and organoleptic qualities. The development of processing technologies aims to minimize nutrient damage. The latest development in food sterilization includes ohmic heating. Ultra-high treatment is effective due to the nature of the reaction that increases the reaction rate with the increased temperature. Chemical reactions are always increased with high temperatures, but enzymes and microorganisms will be inactive at a particular temperature. The thermal process in food preservation is conducted so that foods will have a long storage life.

The selection of the heating system is defined based on several criteria, including characteristics of the product (pH, water activity, and composition), thermal properties of the product (density, viscosity, specific heat, thermal conductivity, thermal diffusivity, electrical conductivity for ohmic heating, and dielectric properties for microwaves), quality of the product, cooling necessities, acceptance criteria for addition/removal of moisture, and cost [43]. The heat transfer mechanism in the thermal processing of foods occurs by convection and conduction. The advance in thermal processing of foods, especially ones related to introducing new tools, packaging materials, and formats, can be re-analyzed, reviewed, and reassessed to improve quality and reduce time and energy consumed during the operation process of the thermal-sterilized products [44]. Several optimization studies have been developed [29], [45], [46]. Optimization aims at maximizing quality retention without major consideration of reducing process operating time and energy consumption or its implications for the production capacity/productivity of the process plant [47].

Thermal processing uses a combination of temperature and time to reduce microorganisms in food products [48]. Thermal processing is necessary to assess several levels of preservation by heating. Thermal processing can give mild or severe heat treatment depending on the heat intensity and application time. Several factors for consideration in selecting thermal processing methods are (1) heat resistance of target microbes, spores, and enzymes, (2) food pH, (3) heating conditions, (4) thermophysical properties of food, (5) container size, and (6) storage conditions following the process [48], [49].

Technology in food preservation continues to develop and starts to replace traditional methods. Electrical heating technology in food processing attracts industrial interests and potentially replaces traditional processes [50]. Electrical heating can be divided into direct electrical heating and indirect electrical heating. In direct electrical heating, an electrical current is applied directly to food products (such as in ohmic heating). Meanwhile, indirect electrical heating (such as heating with radio frequency wave or microwave) first transforms electrical energy into electromagnetic radiation that will produce heat in the product. The recent technology in electrical heating is considered a form of volumetric heating where heat energy is produced directly in foods [51], [52]. A general pattern in heat generation allows for solving overtime cooking time that may result in direct implications for heat and energy efficiency. The main applications of this new heating technology are cooking, pasteurization, sterilization, defrosting and drying. In industry, some of these electrical heating processes (e.g., ohmic heating and radio frequency heating) are used only in temporary situations.

Heat transfer processes can be used to build mathematical relations between the staged heating of foods and the coolest temperature of foods. Some models have been developed for various food processing systems. Similarly, mathematical relation has been developed to describe the thermal inactivation kinetics of microorganisms [53]. Thermal processing that is safe for foods is designed based on two main factors: (i) knowledge of the time-temperature combination needed to inactivate most heat-resistant pathogens, the concern in a particular food product, and (ii) the determination of the heat-penetrating characteristics of a food system, commonly determined by the rate of heat [54]. This information is needed to determine the process schedule, so that pathogen inactivation in food products can be ensured.

Process control is defined as measuring and controlling process variables to achieve desired product attributes. The most important process attribute in many thermal processes is food safety. A suitable system design, implementation, and validation are the key to achieving the result. Automatic control provides better operation consistency, reduced production cost, and improved safety. A process vulnerable to disturbance will have better consistency if the process variable is constantly suited with an automatic control [55], [56].

Improvement in operation consistency can result in products with attributes closer to targeted specifications so that quality can be fully improved. A strict control may also result in fewer products with undesired specifications and help ensure critical safety limits, thereby increasing productivity [57]. Process control presents in two formats, discrete or digital, and continuous or analog. Both modes are commonly operated in a full system. Combining the two forms is usually vital in ensuring that only safe and acceptable products reach consumers. Human variability can be drawn from operations with properly implemented automated control systems [55], [58]. A recent thermal processing technology keeps attracting food manufacturers due to its potential to produce products with better quality, added value, and environmental safety.

Some latest thermal processing technologies are developed to fulfill food health and safety regulations or storage life, minimize temperature's negative effects on organoleptic and nutritional qualities, and combine mild temperature with technology. Recent thermal processing technologies have gained industrial interest and have the potential to replace, or partially replace, traditional preservation methods [59]. Thermal processing technologies with artificial intelligence are rapidly developing. Artificial Neural Network (ANN) in food thermal processing plays a role in controlling temperatures in workstations and locally limited spaces [60], [61], [62]. ANN is a developed mathematical algorithm that allows learning by imitating how the human brain gains and processing knowledge. ANN models contain a superficial computational layer of nodes operating as nonlinear summing tools. These nodes are interconnected with line-weighed connections; weights are adjusted as data is presented to the network [63], [64], [65], [66]. ANN can produce artificial neurons that perform tasks such as predicting output values, classifying objects, approximating functions, recognizing patterns in multifactorial data, and solving known problems (Fig. 2).

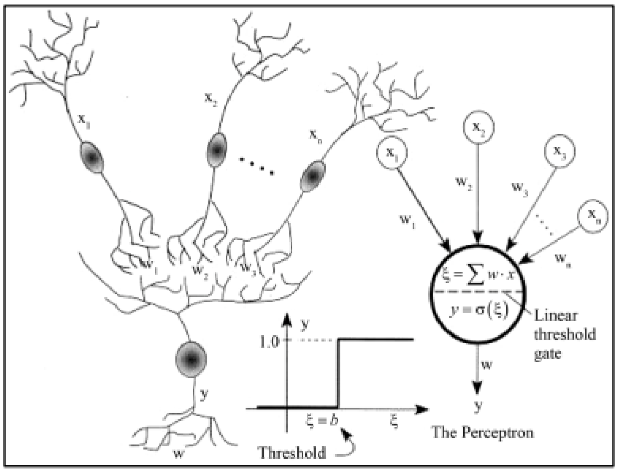

Fig. 2. Similarity and differences between biological neurons and artificial neurons.

As can be seen in Fig. 2, processing units (artificial neurons) consist of a series of x_i entries $(x_1, x_2, \ldots, x_n)$, which are equivalent to dendrites, where information is obtained in the form of an impulse. Meanwhile, weights in w_i synapse are equivalent to delivery mechanisms in biological neurons. The union of these values (x_i and w) is similar to the synapse's inhibitory and excitatory chemical signals, inducing neurons to change their behavior. These values are the gates of the network weighting function that converts values into potential differences. Whereas, the potential difference equals the total signal arriving at dendrites in biological neurons. The weighting function is the sum of the input and synaptic weights. The output of the weighting function comes from the activation function, which converts this value into another form that the output neuron can perform. The output of the network is evaluated in an activation function that triggers an output signal from this neuron to other neighbors [67], [68].

ANN is a computation technology that can be used massively in many applications: control, monitoring, modeling, recognition, detection, pattern analysis, online prediction, image processing, optimization, and signal processing. It can be applied in various aspects, such as manufacturing, agriculture, business management, marketing strategies, pharmaceutical industries, transportation, energy management, economic trading, and food industries [67]. When applied to food thermal processing, ANN can improve product quality, reduce waste, eliminate toxic substances, and control temperatures. Research on the application of ANN in food industries had been conducted by many researchers [69], [70], [71], [72], [73], [74].

Generally, the development of ANN can be divided into four stages: 1) beginning stage, 2) regression stage, 3) resurrection stage, and 4) developed stage. The beginning stage started in the 1940s when the neural network was learned for the first time. In 1943, an American psychologist named McCulloch and a mathematician named Pitts proposed a model called the McCulloch-Pitts model (MP model), which is simple but significant. In the model, the algorithm is realized by considering neurons as functional logic devices, which initiated theoretical research on neural network models. In 1949, Hebb, a psychologist, published "The Organization of Behavior," which contained a hypothesis stating that an intensity of a synaptic connection is a variable. According to the hypothesis, the learning process eventually would happen in the synaptic interface between neurons. The intensity of the synaptic connection varies based on the neuron's activity before and after the synapse. The hypothesis was then developed into Hebb's law, widely known as a common rule in the neural network. Hebb's law tells that the strength of synaptic connections between neurons is a variable and that variability is the basis of learning and memory. Hebb's law is the basis for building a neural network model by learning functions. In 1957, Rosenblatt proposed the Perceptron model based on the MP model. The perceptron model had the basic principle of modern neural networks, and its structure was in harmony with neuropsychology. It was an MP-based neural network model with continuously adjusted weights. After training, it can achieve the purpose of classifying and recognizing certain input vector modes. Although relatively simple, it was the first true neural network. Rosenblatt proved that two-layer sensors could classify inputs and proposed important research directions for three-layer sensors with hidden layer processing elements. Rosenblatt's neural network model contained some of the basic principles of modern neural computing, a major breakthrough in neural network methods and technology. In 1959, some popular American engineers, B. Widrow and M. Hoff et al., proposed the training method of adaptive linear element neural network (Adaline) and Widrow–Hoff learning rule (also known as least-squares deviation algorithm or rule). The proposed method was also applied to an actual project. The result became the first artificial neural network to solve practical problems and promoted the application and development of research on neural networks. The ADALINE network model is a continuous-valued adaptive linear neuron network model that can be used for adaptive systems.

The regression stage was initiated by Minsky and Papert, widely known as founders of artificial intelligence. They conducted learning of mathematical functions and limitations of network systems which were represented by perceptron. In 1969, they showed that the simple linear perceptual function is finite. It could not solve the classification problem of two types of inseparable linear samples. For example, a simple linear sensor could not realize the logical relationship of XOR. This conclusion dealt a heavy blow to artificial neural network research at the time. This started the history of neural networks to 10 years of regression stage. Then, in 1972, Professor Kohonen T. from Finland proposed the Self-Organizing Feature Map (SOM), which became the fundamental principle of developing ANN. SOM network is a tutor-like learning network, mainly used for pattern recognition, speech recognition, and classification problems. It adopted the "winner is king" competitive learning algorithm, which was distinctive from the previously proposed perceptron model. At the same time, the learning and training method is a self-regulating network without training instructions. This learning and training method was often used as training to extract classified information without knowing the existing types of classification. In 1976, Professor Grossberg proposed the famous Adaptive Resonance Theory (ART), which has the characteristics of self-organization and self-stability.

The resurrection stage was started in 1982. Hopfield, an American physicist, proposed a discrete neural network, the Hopfield network, which effectively described neural network research. In this network, the Lyapunov function was introduced for the first time. Researchers later also called the Lyapunov function an energy function. In 1984, Hopfield then proposed an advanced neural network to convert the activation function of neurons from discrete to continuous networks. The Hopfield neural network was a set of nonlinear differential equations. The Hopfield model not only performed a nonlinear mathematical summary of the information storage and retrieval functions of the artificial neural network, but also provided dynamic equations and learning equations. In the Hopfield model, formulas and critical parameters for the network algorithm were introduced, which made the construction and learning of artificial neural networks theoretical under the influence of the Hopfield Model. In 1983, Kirkpatrick realized that annealing simulation algorithms could be used to solve NP-complete combinatorial optimization problems. Hinton and Sejnowsky utilized statistical physics concepts and methods, and firstly proposed a multi-layer network learning algorithm known as the Boltzmann machine model. In 1986, based on the multi-layer neural network model, D.E. Rumelhart et al. proposed the backpropagation algorithm called BP (Error Back Propagation) to solve the weight correction problem of multi-layer neural networks.

The advanced neural network proves that the multi-layer neural network has strong learning ability, and can solve many learning tasks and practical problems. In 1988, Chua and Yang proposed a cellular neural network (CNN) model, a large-scale nonlinear computer simulation system for cellular automata. Kosko had established a two-way associative storage model (BAM) that could learn without supervision. In 1991, Haken introduced synergy to neural networks. In his theoretical framework, Haken believed that cognitive processes were spontaneous and asserted that the process of pattern recognition was a process of pattern formation. In 1994, Liao Xiaoxin expressed the mathematical theory and foundation of cellular neural networks, bringing new advances in this field. By extending the activation function class of neural networks, the more common delayed cellular neural networks (DCNN), Hopfield neural networks (HNN), and bidirectional associative memory networks (BAM) were provided.

After years of development, hundreds of neural network models have been proposed, which denoted the initiation of the developed stage. More precisely, the developed stage was initiated when Deep Learning was first introduced by Hinton et al. in 2006 as a new field in machine learning. Machine learning architecture models with multiple hidden layers were developed at this stage, and more representative characteristic information was obtained through large-scale data training. Deep learning algorithms were used to solve problems in traditional neural networks to limit the number of layers based on the task purpose. ANNs had been used well in many fields, but many aspects still need to be studied. The combination of neural networks with other technologies, such as in distributed memory, parallel processing, self-learning, self-organizing, nonlinear mapping, hybrid methods, and hybrid systems, has recently become a research trend. In food processing, a neural network has been combined with other methods, as seen in Table 2.

TABLE II. COMBINATION OF NEURAL NETWORKS WITH OTHER METHODS IN FOOD PROCESSING

Soft computing combination	Articles' references
Neuro-fuzzy logic	[75], [76] [77-81]
Neuro-Genetic algorithm	[82-88]
Genetic-Neuro-Fuzzy	[22] [89-92]

The combination of neural networks with other methods such as fuzzy logic, expert systems, genetic algorithms, wavelet analysis, chaos, coarse set theory, fractal theory, proof theory, and gray systems have been developed [75], [76]. Other techniques that adopted a combination of neuro-fuzzy algorithms have been successfully developed [77], [78], [79], [80], [81]. Aside of the neuro-fuzzy algorithms, neuro-genetic algorithm was also popularly used [82], [83], [84], [85], [86], [87], [88]. Research even combined the neural networks with GA, such as in a five-layer neural network with GA, used as a learning algorithm. Moreover, comprehensive research discussed fuzzy, Neuro-fuzzy, and Fuzzy-GA and evaluated the reusability of the software component. The results of the Fuzzy-GA outperformed the others when applied as an approximation method. Meanwhile, among various combinations in soft computation methods, the one with the highest visibility at the intersection was fuzzy logic combined with neurocomputing, called neuro-fuzzy systems. A new technique in artificial intelligence has been further developed named neuro-fuzzy genetics (GNF) which is based on the fusion between fuzzy logic, neural networks, and GA [22], [89], [90], [91], [92].

The application of modern soft computing techniques has the potential to enter the development stage of contemporary food products. Recently, soft computing has been studied extensively and applied for scientific research and engineering purposes. Researchers in biology and food engineering have developed several methods (fuzzy logic methods, artificial neural networks, genetic algorithms, decision trees, and supporting vector machines) to study the complex characteristics of many products while adopting cost-effective measures and satisfying production constraints and consumer expectations [93]. Research on the combination of neural networks with other methods in food processing and preservation is rapidly developed [94], [95], [96], [97], [98].

Drying is an important food processing procedure involving simultaneous heat and mass transfer [99]. In order to obtain optimum operating conditions in the online drying process, a mathematical description of heat and mass transfer during the drying process is required. Several studies can be used to calculate the optimal operating conditions using different mathematical models. For instance, the optimum operating conditions in superheated steam drying were evaluated [100]. The researchers solved the mass and energy balance equations and converted them into a generalized initial drying rate equation, in which all characteristics of the dryer were grouped into one dimensionless parameter. However, calculating optimal parameters is sometimes difficult and requires special software, especially when the complexity of the drying process is considered. An empirical model was used for online control of the drying process. For example, an artificial neural network model was developed to rapidly calculate the drying rate [101]. In food industry, researchers have applied the method in many occasions [102], [103], [104], [105]. The advantage of this model class lies in the simple arithmetic operations with well-known input parameters.

However, in many cases, optimal input parameters were unknown when obtaining optimal output. Therefore, this highly relevant work aimed to develop an online strategy for obtaining the optimal operating conditions of the drying process using an artificial neural network. The proposed model optimized operational parameters precisely and quickly with satisfactory performance. The neural network model then can be considered a suitable approach for modeling food preservation [106]. In contrast to conventional (prescriptive) models, which may fail due to the complexity of dynamic processes, neural network-based descriptive models provide an integrated approach that could be applied to the design or optimization of food processing.

IV. CONCLUSIONS

The latest development of research on finding suitable thermal processing without damaging the food quality using artificial intelligence was the utilization of Artificial Neural Network computing technology. ANN provided an integrated approach that could be applied to the design or optimization of food processing. The most developed combination of soft combination methods in food processing is the combination of ANN with fuzzy logic and GA.

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