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Research Article

Computational Modelling for Optimization of Thermosonicated Sohshang (*Elaeagnus latifolia*) Fruit Juice Using Artificial Neural Networks

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The study involved subjecting sohshang (*Elaeagnus latifolia*) juice (SJ) to thermosonications (TS), a process integrating ultrasound and heat, with a range of independent variables. Specifically, three explored distinct amplitudes (30%, 40%, and 50%) alongside three temperature settings (30°C, 40°C, and 50°C) and four treatment durations (15, 30, 45, and 60 minutes) were used in the experiment. A variety of quality parameters were analyzed such as antioxidant activity (AOA), ascorbic acid (AA), total flavonoid content (TFC), total phenolic content (TPC), yeast and mold count (YMC), and total viable count (TVC). Thermosonicated sohshang juices (TSSJ) successfully achieved highest content of AA (69.15 ± 0.99 mg/100 ml), AOA (72.93 ± 1.62%), TPC (122.03 ± 4.23 mg GAE/ml), and TFC (116.14 ± 3.29 mg QE)/ml) under ideal circumstances. Also, minimal TVC and YMC in these juices have been observed. The best results for AA and TFC were observed at 40°C with 40% and 50% amplitude over processing times of 45 and 60 min. To optimize the extraction processes with various objectives, artificial neural network (ANN) was established with an original experimental planning methodology. Overall, the investigation demonstrated that TS is an effective method to enhance the nutritional and microbiological qualities of sohshang fruit juice. The use of ANN in the optimization process is particularly valuable in achieving desirable outcomes. As the food and pharmaceutical industries seek natural and bioactive substances, TSSJ holds great potential for various applications.

1. Introduction

Fruits and vegetables are a good source of vitamins, minerals, and bioactive compounds that contribute to improved overall health. Among the different fruits, underutilized fruits are rich in nutrients and possess therapeutic and medicinal value, providing a wide array of vitamins and minerals [1]. In today's world, consumers are increasingly conscious of the nutritional value of their food and its impact on their health [2]. However, despite the nutritional richness and potential benefits of these underutilized fruits, they remain largely unknown to the outside world due to the lack of awareness and commercialization. Raising awareness and commercializing these fruits can unlock their potential to enhance human health and contribute to the diversity of natural foods available [3].

Sohshang (*Elaeagnus latifolia* L.) (Figures 1(A) and 1(B)) is renowned as one of the most promising underutilized fruit crops in the tribal habitats of India's Northeastern Himalayan region [1]. The fruit has an oblong shape and turns reddish in color when ripe, often being consumed raw by indigenous people. This fruit is a notable source of vitamin C, essential fatty acids, minerals, and other bioactive compounds [2], which supports the immune system and skin

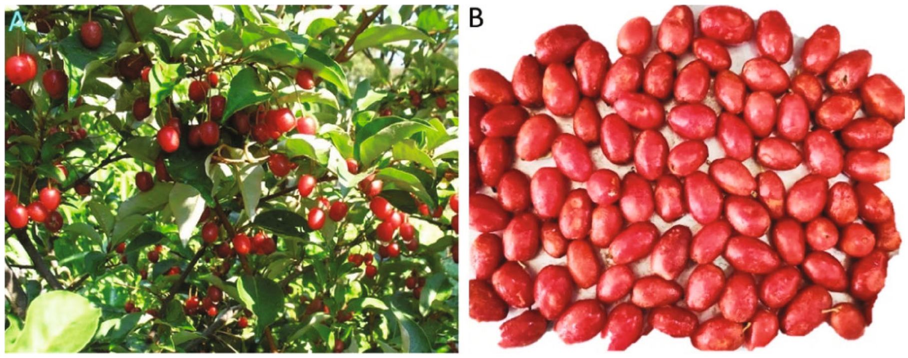

Figure 1: Pictorial representation of sohshang fruits. Fresh sohshang fruits on the tree along with (A) twiggy bushes and (B) fully ripened fresh sohshang fruits.

health. It also provides dietary fiber, aiding in digestion and promoting a feeling of fullness [3]. Additionally, sohshang contains vital minerals like potassium and calcium, important for maintaining healthy bodily functions, including nerve and muscle function and bone health. With a low calorie and fat content, sohshang's natural antioxidants, including flavonoids and phenolic compounds, offer potential health benefits while enhancing its unique flavor [2]. Research has shown that these fruits have the potential to reduce the incidence of cancer and even reverse cancer growth [3]. However, their perishable nature poses a challenge, as they can only be stored for a short period of 2–3 days at room temperature. The delicate texture of the fruit makes it susceptible to damage during handling, marketing, and transportation to distant markets. Consequently, there is a significant loss of these nutrition-rich fruits, leading to economic losses for the farmers. To address these issues and maximize the potential of sohshang fruits, it is crucial to explore processing methods that can create value-added products. Developing value-added products from sohshang fruits is essential to harness their nutritional benefits and support the livelihoods of local farmers.

Fruit juice is an essential product in high demand in the global market. Sohshang juice can be used as a base for making various beverages, such as fruit juices, smoothies, and cocktails. Its unique flavor and nutritional content can add value to these products. It can be incorporated into various food products, including jams, jellies, sauces, and syrups. Its tart and slightly sweet flavor can enhance the taste of these products. It is rich in vitamins, minerals, and antioxidants. It can be used as an ingredient in nutritional supplements like vitamin-enhanced drinks or health shots [3]. However, preserving its quality and safety can be challenging, as it often undergoes deterioration during processing and storage. Traditional methods such as heat treatment have been used to prolong the preservation period of fruit juice by inactivating enzymes and destroying microorganisms [4]. Unfortunately, this process also leads to the degradation of certain nutrients and thermal-labile vitamins due to the application of heat. Moreover, thermal processing can result in the development of undesirable compounds through the Maillard reaction and caramelization. To address these drawbacks, researchers have explored alternative nonthermal technologies to preserve fruit juice quality while maintaining its microbial safety [5]. These technologies include high-pressure processing, magnetic or electric fields, ultrasonication, pulsed electric field, and irradiation. By employing these nonthermal methods, nutritional and sensory losses can be minimized without compromising the product's microbial safety. These innovative approaches offer promising solutions to enhance the quality and safety of fruit juices, meeting the increasing demand for nutritious-rich products in the global market [5].

Thermosonication is a technique that combines moderate heat treatment and acoustic energy (ultrasound wave). This is a novel and practical method that can prolong the shelf life of the item and deactivate microorganisms that are pathogenic, rendering it safe for consumption by humans without changing the product's nutrient makeup or the organoleptic qualities [4]. During thermosonication (TS), bubbles of gas was created inside the fluid as a result of the ultrasound wave (20-100 kHz), and these bubbles exploded during compression, resulting in high temperatures and pressure that may dissolve down substances in the fluid and produce a localized sterilization effect [5]. The level of spoilage and pathogenic microorganisms and enzyme inactivation is determined by the enzyme's nature, process parameters (ultrasound frequency, ultrasound power intensity, pressure, or temperature), medium characteristics (food matrix composition, viscosity), and the kind of tandem and chemical reactions that they establish with other molecules [6]. The combination of heat and ultrasound in thermosonication allows for effective microbial control, enzyme inactivation, enhanced mass transfer, synergistic effects on product quality, and uniform treatment, making it a versatile and powerful process in various food and beverage applications. TS can improve the process of pulling off bioactive substances from plant materials, such as polyphenols from fruits, vegetables, and herbs, or essential oils from aromatic herbs and spices. Various studies have been reported on application of TS on fruit product such as mango [7], apple juice [8], hog plum [9], and soursop juice [10]. An artificial neural network (ANN) is a type of artificial intelligence algorithm designed to mimic the architecture and functions of the brain and spinal cord in humans. The networked nodes, or "neurons," that make up ANNs are in charge of analyzing and transferring data [11]. An ANN is made up of several steps: gathering data, arranging it, developing and testing it sequentially, evaluating its efficacy, and applying it to forecast results from fresh input data. In the framework of demonstrating and optimization, ANNs are able to be employed to develop models of forecasting for intricate structures where traditional mathematical frameworks are not necessarily feasible [12]. It is capable of being utilized to predict important quality characteristics and replicate food manufacturing processes depending on various analyzing factors. By accomplishing this, it will be possible to reduce expenses and generate fewer waste products while improving the circumstances for processing to yield the essential characteristics. It offers a flexible and effective tool for simulations and optimization in many different industries, such as the food processing industry. Numerous investigators have utilized ANN to simulate and optimize variables related to processing for different fruit juices, such as chironji juice [13], Indian jujube [14], and jamun fruit juice [15]. ANN clearly has numerous benefits over response surface methodology and other widely used optimization programmes, including adaptability, nonlinear behaviour robustness, rapid development and modification, absence of previous experience specifications, and broadening. Research on the impact of using TS on the properties of sohshang juice (SJ) is scarce currently. Consequently, the primary goal of this research was to investigate the impact of ultrasound amplitude and temperature in the TS process on various attributes of SJ, including ascorbic acid levels, flavonoid content, phenolic content, and antioxidant activity. Additionally, it was aimed at optimizing the process parameters using ANNs.

2. Material and Methods

2.1. Sohshang (Elaeagnus latifolia L.) Fruit Sample. Matured and fresh sohshang fruit was collected from Ranipool, Sikkim, and brought in a container that was insulated (a sterilized insulated ice container kept at 4°C) to the Department of FET (Food Engineering and Technology) lab at CITK, Kokrajhar. After being cut off from their stalks, the fruits were thoroughly cleaned in water and allowed to dry in air. The fruits were sliced into tiny pieces in order to extract the juice.

2.2. Chemicals Used during Experimentation. The experimental chemicals were obtained from two different sources: Sigma-Aldrich (India) and HiMedia Chemicals (India). The MERCK Group, Germany, provided the specific chemicals needed for the determination of microbiological properties, including total plate count agar, peptone water, and potato dextrose agar.

2.3. Preparation of Juice Samples. The sohshang fruit slices, fair size of 2-3 cm, were ground using a household grinder (mixer). Subsequently, the juice was clarified and any remaining impurities were removed using Whatman® filter paper no. 1. The extracted juice was then divided into three separate categories: the raw juice (control), the pasteurized sohshang juice (PSSJ), and the thermosonicated sohshang juice (TSSJ). On the same day, each juice sample underwent processing immediately after extraction.

2.4. Pasteurization of the Juices. In this study, sohshang fruit juices were subjected to thermal treatment using a vertical pasteurizer (Mac-Autoclave Vertical model, Macro Scientific Works Pvt. Ltd., Delhi, India). The pasteurization process involved exposing the juices to a precisely maintained temperature at 90°C for 1 min [16]. The samples were then rapidly cooled down in an ice bath. The selection of these pasteurization conditions is aimed at replicating the commercial extraction of juices, where temperatures in the range of 90-95°C are commonly utilized for 15 to 60 s. This commercial approach efficiently reduces the microbial load by up to 5 log units, ensuring the final product's safety and quality while preserving its nutritional attributes [16].

2.5. TS of the Juices. TS treatments were administered with an ultrasonicator probe to the juice samples (Sonics & Materials, Inc., Newton, CT, USA) with a full power output of 750 W [17]. Each treatment involved subjecting 100 ml of juice samples to three different amplitudes, 30%, 40%, and 50%, for varying durations of 15, 30, 45, and 60 min [18] at different temperatures of 30°C, 40°C, and 50°C. To maintain the integrity of the samples, the sonication process was carried out in the dark, minimizing the potential for any correspondence with surrounding light. The resulting SJ samples obtained were meticulously shifted into sterilized containers after the ultrasound treatment, and they were kept in the refrigerator at 4°C until additional analysis was performed.

2.6. Physicochemical Property Determination

2.6.1. pH, Total Soluble Solid, and Titratable Acidity. Using a digital pH metre, the pH level of SJ samples was determined at 25 ± 1°C [19]. Using a refractometer, the level of total soluble solids (TSS) in SJ was measured; the results were expressed as °Brix [20]. The titratable acidity (TA) of SJ was analyzed using the AOAC [21] method, and the result was expressed as %.

2.6.2. Cloudiness and Browning Index. The cloudiness (CI) and browning index (BI) of raw, PSSJ, and TSSJ were determined by following the procedure of Krishnan et al. [22]. For cloudiness determination, a wavelength in the visible range, such as 600 nm, was selected. The spectrophotometer was calibrated using a blank reference, and the absorbance of the sample was measured. For browning index determination, specific wavelengths associated with color changes, such as 420 nm for yellow-brown color or 475 nm for general browning, were chosen. The spectrophotometer was again calibrated, and absorbance measurements were taken for the samples.

2.7. Analyzation of the Functional Characteristics

2.7.1. Ascorbic Acid Content. Iodine titration, as outlined by Basumatary et al. [23], was used to determine the ascorbic acid content (AA) of the specimens and expressed as mg/100 ml. A standardized iodine solution was prepared by dissolving potassium iodate in a solution containing potassium iodide and dilute sulfuric acid. The ascorbic acid sample, previously dissolved in a suitable solvent, was titrated with excess iodine solution. The reaction between ascorbic acid and iodine produced dehydroascorbic acid and iodide ions. The excess iodine was titrated back with a sodium thiosulfate solution until the solution became pale yellow. A starch indicator was introduced to the flask, turning the solution blue as the titration approached completion. The endpoint was reached when the blue color disappeared, signaling the reaction's completion.

2.7.2. Total Phenolic Content. The assessment of TPC, or total phenolic content, in samples was conducted using Nayak et al. [25] and expressed as mg GAE/ml of sample. TPC was carried out utilizing the spectrophotometric Folin-Ciocalteu assay. Juice samples were mixed with the Folin-Ciocalteu reagent and sodium carbonate, initiating a colorimetric reaction. Following a specified incubation period, the resulting blue complex's absorbance was measured at 765 nm using spectrophotometer.

2.7.3. Total Flavonoid Content. Samples' total flavonoid content (TFC) was ascertained according to Basumatary et al. [26] and expressed as mg QE/ml of sample. TFC was conducted through the spectrophotometric method employing aluminum chloride. Juice samples were mixed with a solution of aluminum chloride and potassium acetate, initiating a colorimetric reaction. A UV spectrophotometer was used to determine the complex's absorbance at 415 nm as soon as the incubation period was completed.

2.7.4. Antioxidant Activity. Using the Denev et al. [24] outlined protocol, the samples' antioxidant activity (AOA) was evaluated by scavenging them with DPPH (2,2-diphenyl-1-picrylhydrazyl). Using an instrument called a spectrophotometer, the absorbance of the resultant solution was determined at 517 nm following a period of incubation.

2.8. Identifying the Characteristics of Microbes. To evaluate the total viable counts (TVC) and total yeast and mold counts (YMC) of SJ, microbiological analysis was performed, following the methodology outlined in the work of Kijpatanasilp et al. [27]. TVC and YMC were analyzed using plate count agar (PCA) and potato dextrose agar (PDA), respectively. Initially, samples were prepared and subjected to appropriate dilutions to ensure countable colonies within the detectable range. For total viable count, the diluted samples were plated on PCA, and after incubation, the visible colonies were enumerated.

2.9. Experimental Design for Optimization

2.9.1. Artificial Neural Network Modelling. MATLAB R2020a software was used to develop the mathematical models for analyzing the physicochemical, functional, and microbial properties of TSSJ. The input parameters and their appropriate ranges were established during the preliminary stage through careful analysis. TS amplitude (X1) with values of 30%, 40%, and 50%, TS temperature (X2) with options of 30°C, 40°C, and 50°C, and sonication time (X3) ranging from 15 to 60 min were selected as the independent variables for the data analysis. The preliminary study was performed to examine treatment temperatures between 30 and 50°C. By consulting earlier studies that had successfully used ultrasonication to extract various fruit juices, this temperature range was chosen [28, 29]. The fitness of ANN models was evaluated using coefficient of determination (R^2), mean absolute error (MAE), and mean square error (MSE) values, which were determined using the following [28].

$$R^2 = \left[\left(\frac{\sum_{i=1}^{n}(x_i-\bar{x})(y_i-\bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i-\bar{x})^2}\sqrt{\sum_{i=1}^{n}(y_i-\bar{y})^2}}\right)\right],$$
$$\mathrm{MAE} = \left[\left(\frac{1}{n}\sum_{i=1}^{n}(x_i-y_i)\right)\right], \quad (1)$$
$$\mathrm{MSE} = \left[\frac{1}{n}\sum_{i=1}^{n}(x_i-y_i)^2\right].$$

In this case, the statistics that are used are x_i for the data from the experiment, y_i for the values that are expected, n for the overall number of observations, and x for the average value of the data collected during the experiment.

2.10. Statistical Analysis. All the experiments were performed in triplicate and were presented as mean ± standard deviation. Statistical analysis was conducted using analysis of variance (ANOVA) using the SPSS 16.0 (IBM, SPSS Inc., USA). Duncan's multiple range test was applied to identify significant differences at a significance level of $p < 0.05$.

3. Result and Discussion

3.1. Physicochemical Properties. In the present study, the pH, TSS, and TA of the raw juice were found to be insignificantly different from the pasteurized juice (Table 1). This finding aligns with the results reported by Oladunjoye and Awani [30]. Similarly, for the TSSJ, the effect of temperature on pH, TSS, and TA was insignificant ($p > 0.05$) as shown in Table 2. These results are consistent with the findings of earlier studies [31–33]. pH, TSS, and TA values of the thermosonicated juice ranged from 3.53 ± 0.48 to 3.86 ± 0.91, 11.02 ± 1.97 to 13.34 ± 0.58°Brix, and 3.27 ± 0.85 to 3.80 ± 0.21%, respectively.

3.2. Cloudiness (CI) and Browning Index (BI). The turbidity and suspended particles (cellulose, pectin, protein, hemicellulose, lipids, and other minor components) in the juice are measured by the juice's CI. Fruit juices' color and flavor can be greatly affected by the presence of these particles. The study found that there was no discernible difference between the fresh juice and the pasteurized juice's CI value ($p > 0.05$). This finding aligns with the results reported by Lepaus et al.

Table 1: Comparison of the quality parameters of raw and pasteurized sohshang fruit juice[1].

Parameters	Raw juice	Pasteurized juice
pH	4.02 ± 0.84^a	3.92 ± 0.23^a
TSS (°Brix)	13.00 ± 0.00^a	13.00 ± 0.00^a
TA (%)	3.18 ± 0.71^a	3.23 ± 0.83^a
Cloudiness	0.947 ± 0.038^a	0.970 ± 0.033^a
Browning index	0.088 ± 0.031^a	0.094 ± 0.043^a
Ascorbic acid (mg/100 ml)	60.27 ± 2.24^a	46.30 ± 6.98^b
Antioxidant activity (%)	46.93 ± 0.73^a	44.44 ± 2.66^b
TPC (mg GAE/ml)	80.75 ± 3.71^a	70.84 ± 3.45^b
TFC (mg QE/ml)	64.04 ± 2.13^a	51.81 ± 2.40^b
Total viable count (log CFU/ml)	3.82 ± 0.18	ND
Yeast and mold count (log CFU/ml)	2.84 ± 0.03	ND

[1]Data are presented as mean ± standard deviation of three independent replications. Mean values with different lowercase superscripts in the same row (a, b) are significantly different ($p < 0.05$) from each other. ND: not detected; GAE: gallic acid equivalents; QE: quercetin equivalent; TA: titratable acidity; TFC: total flavonoid content; TPC: total phenolic content; TSS: total soluble solids; CFU: colony forming unit.

[34], who also found that pasteurization had no significant effect on the CI of the juice. However, the CI value of the TSSJ (ranging from 1.07 to 1.68) was higher compared to both the fresh (0.947 ± 0.038) and pasteurized (0.970 ± 0.033) juices. The CI of the juice increased with the treatment temperature, time, and amplitude of the TS process, and this effect was found to be significant. Lepaus et al. [34] published findings that were comparable. This increase in CI may be attributed to the disintegration of cavitation causing bigger molecules to split into smaller ones, resulting in the development of mechanical force [35]. The changes in cloudiness observed in the TSSJ could have implications for its sensory attributes and overall acceptance.

The BI of the raw juice (0.088 ± 0.031) and PSSJ (0.094 ± 0.043) showed insignificant variation (Table 1). However, the browning index of the TSSJ was higher than that of the raw and PSSJ, ranging from 1.07 to 0.272. Similar to CI, the BI of the juice significantly increased with higher treatment temperature, time, and amplitude. These findings are consistent with other studies [36], which also reported a similar trend of increased browning index with TS. The rise in BI during TS can be attributed to the development of the Maillard reaction that may contribute to changes in color during thermosonication of juice including natural sugars, amino acids, protein, and some intermediate compounds [30]. Previous studies have reported different reasons for the occurrence of the BI, including the breakdown of carotenoid pigment, degradation of ascorbic acid, enzymatic reactions (involving polyphenol oxidase and peroxidase), nonenzymatic reactions (such as the Maillard reaction), and breakdown of carotenoid pigments [34–36]. The observed increase in browning index during TS highlights the need for careful optimization of processing parameters to manage color changes and preserve the overall quality of the juice.

3.3. Impact of Processing Treatments on the Nutritional Attributes of SJ

3.3.1. Ascorbic Acid. The impact of TS on the AA levels of SJ is depicted in Figure 2. Untreated fruit juice and PSSJ were measured for their AA content as 60.27 ± 2.24 mg/100 ml and 46.30 ± 6.98 mg/100 ml, respectively. As distinguished from fresh SJ, the AA levels in PSSJ were lower. However, the TSSJ samples had a higher retention of AA, varying from 54.64 ± 2.56 to 69.15 ± 0.99 mg/100 ml, compared to the PSSJ samples depicted in Figure 2. The highest accumulation of AA concentration in TSSJ, amounting to 69.15 ± 0.99 mg/100 ml, was achieved under specific conditions: 40% X1, 40°C X2, and 45 min X3. TSSJ has lower AA levels than raw juices, which can be explained through AA's sensibility to heat and SJ's elevated water dissolution. Additionally, the retention of AA in TSSJ was greatly aided by using mild/low temperatures during sonication as opposed to the significant loss suffered by untreated SJ during traditional pasteurization processes [37]. It is crucial to remember that AA is a heat-sensitive substance that breaks down quickly at higher analyzing conditions; for this reason, it works best at lower implementation of temperature levels [37]. While some AA can be lost as a consequence of the process of oxidation, cell wall breaks down leading to the release of vitamin C into the juice throughout TS implementation which may also be responsible for the rise in the preservation of AA content in TSSJ [38]. Furthermore, the depletion of O_2 dissolved throughout cavitation might be linked to an increase in AA content, given that many researches have shown enhanced AA accumulation in juice from fruit specimens during TS [37, 38].

3.3.2. Total Phenolic Content. Figure 3 presents the experimental results of the assessment of TPC in samples. The study revealed that raw juice exhibited a higher TPC than PSSJ, with levels of 80.75 ± 3.71 mg GAE/ml and 70.84 ± 3.45 mg GAE/ml, respectively. Remarkably, TS significantly increased TPC ($p < 0.05$) across three amplitude levels (30%, 40%, and 50%). Surprisingly, the highest level of TPC was achieved in TSSJ, reaching 122.03 ± 4.23 mg GAE/ml. This peak value was observed at 50% amplitude, 30°C temperature, and 60 min. These findings underscore the effectiveness of TS in augmenting the TPC of SJ, thereby enhancing its potential health-promoting properties. The increase in TPC through TS indicates the preservation of valuable phenolic compounds in the juice, which are known for their antioxidant and health benefits. This study highlights the potential of TS as a valuable processing technique to improve the nutritional and functional qualities of SJ, making it an attractive option for health-conscious consumers.

As depicted in Figure 3, the investigation revealed that TSSJ had a significantly higher TPC as compared to both raw and PSSJ. This finding aligns with earlier research [38], which hypothesized that the increase in TPC after TS might be attributed to the removal of restricted oxygen molecules from the SJ samples. Furthermore, the study indicated that the TPC at each amplitude level was significantly

Table 2: Impact of TS at 30, 40, and 50% amplitude on pH, TSS, TA, cloudiness, and browning index of sohshang juice[1].

Parameters	Amplitude (%)	30°C 15	30°C 30	30°C 45	30°C 60	40°C 15	40°C 30	40°C 45	40°C 60	50°C 15	50°C 30	50°C 45	50°C 60
pH	30	3.86 ± 0.91^{aA}	3.81 ± 0.63^{aA}	3.77 ± 0.46^{aA}	3.71 ± 0.64^{aA}	3.83 ± 0.25^{aA}	3.76 ± 0.72^{aA}	3.73 ± 1.18^{aA}	3.70 ± 0.45^{aA}	3.80 ± 0.28^{aA}	3.70 ± 0.65^{aA}	3.66 ± 0.61^{aA}	3.64 ± 0.37^{aA}
	40	3.80 ± 0.41^{aB}	3.77 ± 0.95^{aB}	3.69 ± 0.37^{aB}	3.62 ± 0.62^{aB}	3.79 ± 0.54^{aB}	3.72 ± 0.40^{aB}	3.68 ± 0.41^{aB}	3.62 ± 0.31^{aB}	3.69 ± 0.42^{aB}	3.67 ± 0.90^{aB}	3.63 ± 0.62^{aB}	3.61 ± 0.67^{aB}
	50	3.77 ± 1.22^{aB}	3.70 ± 0.94^{aB}	3.63 ± 0.82^{aB}	3.57 ± 0.63^{aB}	3.66 ± 0.39^{aB}	3.60 ± 0.38^{aB}	3.58 ± 0.82^{aB}	3.53 ± 0.60^{aB}	3.61 ± 0.47^{aB}	3.55 ± 0.68^{aB}	3.53 ± 0.51^{aB}	3.53 ± 0.48^{aB}
TSS	30	12.97 ± 0.06^{aA}	13.01 ± 0.02^{aA}	12.75 ± 0.61^{aA}	10.73 ± 2.66^{aA}	13.13 ± 0.32^{aA}	13.03 ± 0.56^{aA}	12.98 ± 0.13^{aA}	12.99 ± 0.01^{aA}	11.24 ± 1.53^{aA}	12.50 ± 1.00^{aA}	12.03 ± 0.91^{aA}	11.35 ± 2.78^{aA}
	40	11.50 ± 3.38^{aA}	12.14 ± 1.02^{aA}	12.63 ± 0.32^{aA}	13.01 ± 0.02^{aA}	12.45 ± 1.36^{aA}	12.63 ± 0.81^{aA}	12.52 ± 1.33^{aA}	12.97 ± 1.05^{aA}	11.32 ± 1.68^{aA}	11.59 ± 1.29^{aA}	13.00 ± 1.00^{aA}	13.01 ± 1.04^{aA}
	50	12.53 ± 0.50^{aA}	12.87 ± 0.24^{aA}	12.70 ± 0.61^{aA}	13.34 ± 0.58^{aA}	11.02 ± 1.97^{aA}	12.67 ± 1.53^{aA}	12.99 ± 0.99^{aA}	12.69 ± 0.60^{aA}	13.01 ± 0.05^{aA}	12.99 ± 0.01^{aA}	12.93 ± 0.89^{aA}	13.04 ± 0.08^{aA}
TA	30	3.27 ± 0.85^{aA}	3.32 ± 0.14^{aA}	3.35 ± 0.61^{aA}	3.38 ± 0.68^{aA}	3.37 ± 0.35^{aA}	3.40 ± 0.54^{aA}	3.42 ± 0.57^{aA}	3.44 ± 0.72^{aA}	3.43 ± 0.70^{aA}	3.46 ± 0.73^{aA}	3.49 ± 0.47^{aA}	3.52 ± 0.53^{aA}
	40	3.34 ± 0.82^{aB}	3.36 ± 0.73^{aB}	3.39 ± 0.86^{aB}	3.41 ± 0.64^{aB}	3.43 ± 0.81^{aB}	3.46 ± 0.87^{aB}	3.48 ± 0.48^{aB}	3.51 ± 0.66^{aB}	3.54 ± 0.88^{aB}	3.57 ± 0.66^{aB}	3.63 ± 0.71^{aB}	3.68 ± 0.58^{aB}
	50	3.41 ± 0.47^{aC}	3.44 ± 0.55^{aC}	3.47 ± 1.21^{aC}	3.51 ± 1.20^{aC}	3.56 ± 1.35^{aC}	3.63 ± 0.69^{aC}	3.73 ± 0.69^{aC}	3.80 ± 0.21^{aC}	3.72 ± 0.60^{aC}	3.75 ± 0.38^{aC}	3.76 ± 0.51^{aC}	3.74 ± 0.65^{aC}
CI	30	1.070 ± 0.022^{hA}	1.083 ± 0.051^{hA}	1.147 ± 0.024^{ghA}	1.231 ± 0.084^{efgA}	1.117 ± 0.023^{ghA}	1.211 ± 0.078^{fgA}	1.351 ± 0.034^{cdeA}	1.401 ± 0.003^{bcdA}	1.299 ± 0.011^{defA}	1.432 ± 0.044^{abcA}	1.489 ± 0.010^{abA}	1.536 ± 0.043^{aA}
	40	1.350 ± 0.041^{cB}	1.396 ± 0.090^{cB}	1.413 ± 0.066^{bcB}	1.423 ± 0.022^{bcB}	1.389 ± 0.010^{cB}	1.442 ± 0.026^{bcB}	1.477 ± 0.029^{abcB}	1.544 ± 0.047^{abB}	1.595 ± 0.007^{aB}	1.617 ± 0.014^{aB}	1.622 ± 0.077^{aB}	1.622 ± 0.077^{aB}
	50	1.513 ± 0.001^{dC}	1.560 ± 0.034^{cdC}	1.575 ± 0.032^{bcdC}	1.619 ± 0.016^{abcC}	1.410 ± 0.013^{eC}	1.557 ± 0.049^{cdC}	1.581 ± 0.013^{abcdC}	1.597 ± 0.019^{abcdC}	1.644 ± 0.074^{ab}	1.664 ± 0.018^{abC}	1.676 ± 0.029^{aC}	1.676 ± 0.029^{aC}
BI	30	0.107 ± 0.040^{bA}	0.119 ± 0.071^{abA}	0.149 ± 0.038^{abA}	0.180 ± 0.029^{abA}	0.147 ± 0.036^{abA}	0.170 ± 0.020^{abA}	0.189 ± 0.019^{abA}	0.200 ± 0.051^{aA}	0.173 ± 0.036^{abA}	0.206 ± 0.026^{abA}	0.216 ± 0.016^{abA}	0.224 ± 0.030^{abA}
	40	0.151 ± 0.043^{aB}	0.179 ± 0.057^{aB}	0.187 ± 0.064^{aB}	0.196 ± 0.072^{aB}	0.180 ± 0.060^{aB}	0.192 ± 0.065^{aB}	0.198 ± 0.071^{aB}	0.213 ± 0.083^{aB}	0.202 ± 0.080^{aB}	0.223 ± 0.027^{aB}	0.244 ± 0.022^{aB}	0.256 ± 0.048^{aB}
	50	0.182 ± 0.059^{aC}	0.203 ± 0.050^{aC}	0.212 ± 0.084^{aC}	0.217 ± 0.086^{aC}	0.206 ± 0.063^{aC}	0.211 ± 0.082^{aC}	0.222 ± 0.030^{aC}	0.229 ± 0.050^{aC}	0.220 ± 0.006^{aC}	0.252 ± 0.040^{aC}	0.267 ± 0.119^{aC}	0.272 ± 0.051^{aC}

[1]Data are presented as mean ± standard deviation of three independent replications. Mean values with different lowercase superscripts in the same row (a–l) and uppercase superscripts (A-C) within column are significantly different ($p < 0.05$) from each other. TA: titratable acidity; TSS: total soluble solid; TS: thermosonication.

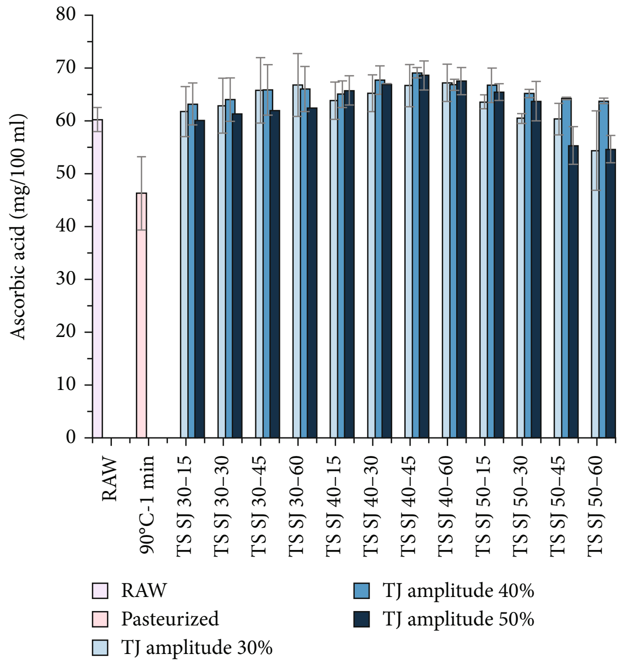

Figure 2: Effects of pasteurization and TS (30, 40, and 50% amplitude) on ascorbic acid levels of sohshang juice. Raw, untreated sample; 90-1, pasteurized SJ (sohshang juice); TSSJ, thermosonicated sohshang juice; 30-15, TSSJ at 30°C for 15 min; 30-30, TSSJ at 30°C for 30 min; 30-45, TSSJ at 30°C for 45 min; 30-60, TSSJ at 30°C for 60 min; 40-15, TSSJ at 40°C for 15 min; 40-30, TSSJ at 40°C for 30 min; 40-45, TSSJ at 40°C for 45 min; 40-60, TSSJ at 40°C for 60 min; 50-15, TSSJ at 50°C for 15 min; 50-30, TSSJ at 50°C for 30 min; 50-45, TSSJ at 50°C for 45 min; and 50-60, TSSJ at 50°C for 60 min.

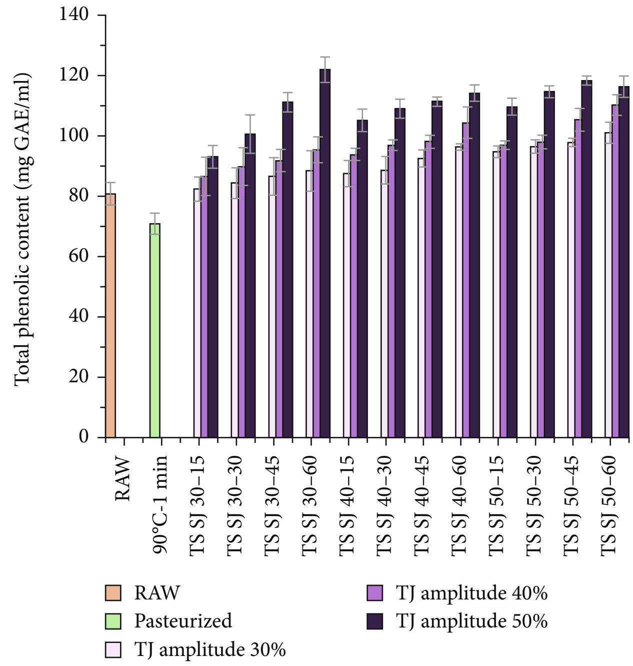

Figure 3: Effects of pasteurization and TS (30, 40, and 50% amplitude) on total phenolic content of sohshang juice. TS: thermosonication; TPC: total phenolic content; GAE: gallic acid equivalent; SJ: sohshang juice. For sample codes, refer to Figure 2.

influenced by the treatment temperature ($p < 0.05$). Notably, higher amplitude and temperature during TS were found to enhance TPC levels in SJ.

Ultrasound can enhance mass transfer within the juice, promoting the diffusion of phenolic compounds from the plant matrix into the liquid phase. The agitation caused by ultrasonic waves helps in overcoming mass transfer limitations, increasing the efficiency of extraction [22]. The combination of heat and ultrasound in thermosonication can have a synergistic effect pertaining to the purification of phenolic compounds. Heat can increase the solubility of certain compounds, while ultrasound can aid in their release [27]. The mechanical effects of ultrasound, including cavitation and microstreaming, contribute to the breakdown of plant cell structures. This disruption allows for better access to phenolic compounds, enabling their extraction [22]. Ultrasound has a stabilizing effect on certain phenolic compounds, potentially protecting them from degradation during thermal processing [38].

The increase in TPC of TSSJ can be attributed to several factors. One possible reason is the transition of phenolic composition extracted from their restricted to free form states induced by cavitation [38]. Furthermore, cavitation-induced breakdown of cell membranes during TS may result in the release of phenolic substances, which raises TPC [37]. Experimental studies by Krishnan et al. [22] and Basumatary et al. [23] have also shown that the formation of microcavities during TS can improve the mass movement and further helps to the rise in TPC. These combined effects highlight the potential of TS as a promising method to boost the total phenolic content of SJ, thereby enhancing its nutritional and health-promoting properties.

3.3.3. Total Flavonoid Content. The study investigated the effects of pasteurization and TS on the TFC of SJ which are illustrated in Figure 4. The TFC values of control sample and PSSJ were 64.04 ± 2.13 and 51.81 ± 2.40 mg QE/ml, respectively. Remarkably, the TFC values of TSSJ samples (ranging from 67.55 ± 1.30 to 116.14 ± 3.29 mg QE/ml) were found to be significantly higher compared to both control and PSSJ samples. The highest flavonoid content was achieved with an amplitude of 50%, temperature of 40°C, and a 60 min treatment (116.14 ± 3.29 mg QE/ml), while the lowest levels were observed with an amplitude of 50%, temperature of 40°C, and a 45 min treatment (108.12 ± 4.03 mg QE/ml), as well as an amplitude of 50%, temperature of 50°C, and a 60 min treatment (107.85 ± 1.79 mg QE/ml). Ultrasonication can lead to the expulsion of phenolic and flavonoid compounds from plant cells due to the cavitation established around the particles [39]. The absorption of the flavonoids from the plant substance into the extracted juice is enhanced by greater ultrasound intensity, which raises the extraction effectiveness overall. The precise temperature and time parameters applied in the TS process are likely to safeguard flavonoid compounds from degradation or denaturation, thereby augmenting their stability and preservation.

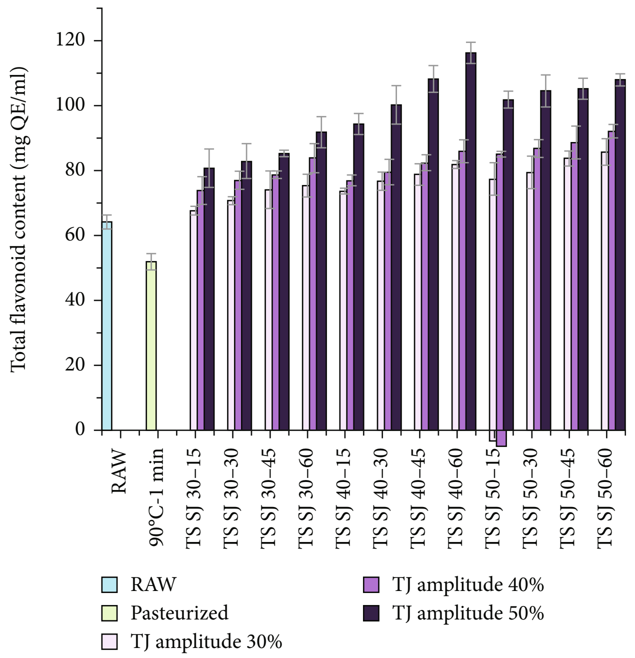

Figure 4: Effects of pasteurization and TS (30, 40, and 50% amplitude) on total flavonoid content of sohshang juice. TFC: total flavonoid content; QE: quercetin equivalent; TS: thermosonication; SJ: sohshang juice. For sample codes, refer to Figure 2.

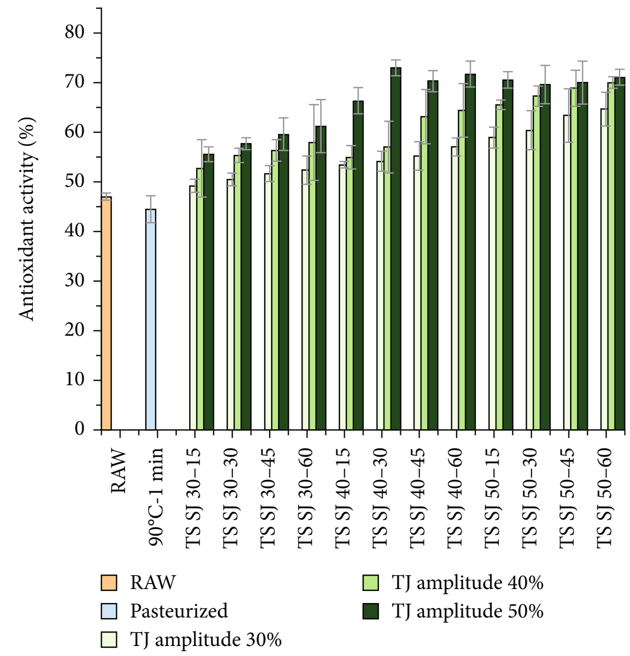

Figure 5: Effects of pasteurization and TS (30, 40, and 50% amplitude) on antioxidant activity levels of sohshang juice. TS: thermosonication; SJ: sohshang juice. For sample codes, refer to Figure 2.

Ultrasonic waves generate cavitation bubbles in the liquid, and upon collapse, these bubbles create localized shockwaves and microjets. This mechanical action contributes to the disruption of plant cell structures, facilitating the release of flavonoids trapped within the cells. Ultrasound promotes efficient mass transfer within the juice, enhancing flavonoid compound dissemination out of the plant's matrix into the liquid phase. The agitation caused by ultrasound waves helps overcome mass transfer limitations, leading to improved extraction. The combination of heat and ultrasound in thermosonication has a synergistic impact on flavonoid extraction. Heat increases the solubility of certain compounds, while ultrasound aids in their release from plant tissues. The mechanical effects of ultrasound contribute to the breakdown of plant tissues, increasing the accessibility of flavonoids and facilitating their extraction. Furthermore, the addition of hydroxyl molecules to the volatile phenolic substances ring structure brought about by TS might be a factor in the rise in both TFC and TPC levels [38]. Similar findings regarding the enhancement of flavonoid levels have been reported by several researchers [40]. These outcomes highlight the potential of TS as an effective technique to maximize the flavonoid content in SJ, potentially enhancing its nutritional and health benefits.

3.3.4. Antioxidant Activity. Figure 5 illustrates the effect of PS and TS on the AOA of SJ samples. The raw juice exhibited an AOA value of $46.93 \pm 0.73\%$, while the PSSJ showed a slightly lower value of $44.44 \pm 2.66\%$. The decrease in AOA observed in PSSJ can be attributed to the use of high temperatures during the juice preparation process. Prolonged exposure to such high temperatures might lead to the loss of important vitamins and carotenoids, such as vitamin C, contributing to the decline in antioxidant activity. The results highlight the importance of maintaining SJ's beneficial elements through gentle and efficient TS techniques in order to preserve its ideal antioxidant qualities. As depicted in Figure 5, TSSJ exhibited higher retention of AOA compared to both fresh and PSSJ samples. Notably, the enhanced AOA in SJ was correlated with increased treatment amplitude and time. Particularly, TSSJ treated at 40°C for 30 minutes with a 50% amplitude showed a significantly higher AOA value of $72.93 \pm 1.62\%$. The increased TPC in SJ after sonication might have resulted from the synthesis of hydroxyl groups within the aromatic structure of phenolic compounds. The higher TPC quantities in the treated juices are likely a result of processes induced by sonication that encourage the production of these hydroxyl groups. Resonant stabilization of phenolic compounds is more feasible when these hydroxyl radicals are present because they increase the electron density in the aromatic ring. These hydroxyl radicals' existence increases the electron density in the aromatic ring, making the phenolic compounds more amenable to resonance stabilization. As a result, the phenolic compounds' reactivity to free radicals is reduced, boosting their overall antioxidant potential [38]. Previous research has highlighted the crucial role of cavitation phenomena during TS in enhancing the accessibility and separation of phenolic molecules, leading to a notably higher AOA content in TSSJ [36, 37]. These findings emphasize the significant contribution of cavitation processes in improving the juice's bioactive qualities, thereby highlighting the potential benefits of TS as a promising method to enhance its overall functional qualities. Studies

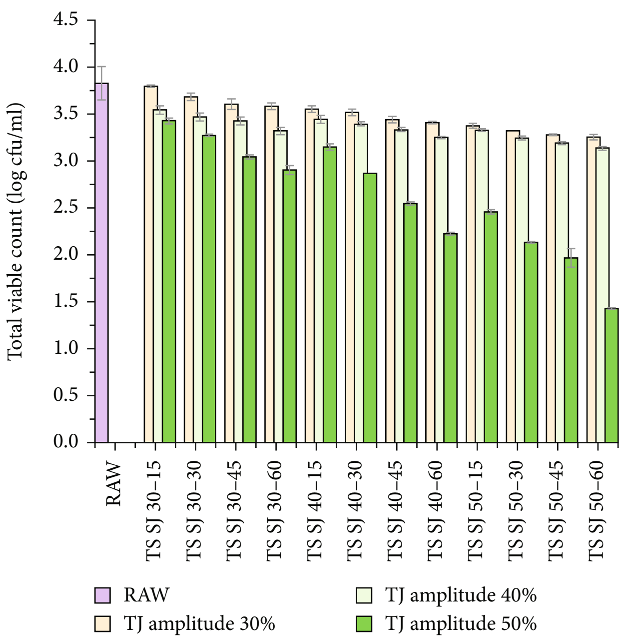

Figure 6: Effects of pasteurization and TS (30, 40, and 50% amplitude) on TVC of sohshang juice. TS: thermosonication; CFU: colony forming unit; TVC: total viable content; SJ: sohshang juice. For sample codes, refer to Figure 2.

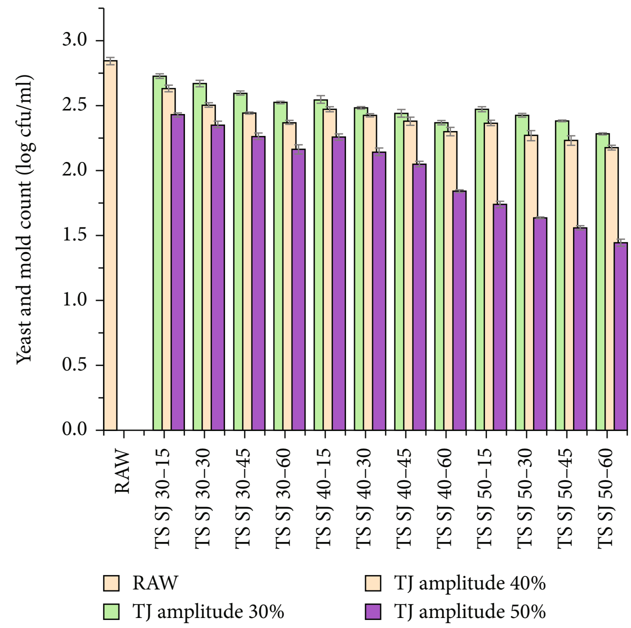

Figure 7: Effects of pasteurization and TS (30, 40, and 50% amplitude) on yeast and mold count of sohshang juice. TS: thermosonication; CFU: colony forming unit; SJ: sohshang juice. For sample codes, refer to Figure 2.

have demonstrated a favorable enhancement in the extraction of phenolic compounds within the temperature range of 40-50°C due to the promotion of diffusion and dispersion of solutes. Temperatures above 60°C should be used with caution, though, as they may cause these beneficial phenolic compounds to become denaturized. TS has been proven to be a valuable technique for increasing the AOA in various fruit juice samples. For instance, studies have shown that it successfully improved AOA in juices made from fruits like chironji fruit [13] and lime fruit [21]. These findings further establish TS as a promising approach to enhance the antioxidant properties of SJ and other fruit juices, paving the way for the development of healthier and more functional juice products.

3.4. Processing's Effect on Sohshang Juices' Microbial Counts. Figures 6 and 7 show how TS was applied to microbial counts. The raw juice had TVC and YMC of 3.82 ± 0.18 and 2.84 ± 0.03 log CFU/ml, respectively, before any treatment. In line with earlier studies on different fruit juices, PSSJ totally deactivated yeast and mold populations as well as microbial populations (not detectable (ND)) [41].

The microbes found in the juice undergo damage to their cell walls, DNA, and structure of proteins during the high temperatures of pasteurization. Microbes that are harmed in this way may undergo cytolytic reactions that lead to their eventual eradication. Microorganisms' unstable cell membranes break down and rupture when heated, allowing the biological material of the cells to diffuse [42]. The effect of PS as well as TS on the TVC along with YMC of SJ is depicted in Figures 6 and 7. Compared to the fresh SJ samples, the TSSJ's TVC was lower (3.82 ± 0.18 log CFU/ml), in the range of 3.79 ± 0.18 to 1.43 ± 0.02 log CFU/ml. Either a rise in temperatures or amplitude will result in a decline in TVC population. One of the physical processes is the cavitation bubbles, which are created when ultrasound waves rapidly expand and contract in a liquid medium. The elevated pressures and shock waves from these bubbles can damage the cell membranes and walls of the bacteria and make them no longer active. In addition to its physical functions, TS also works chemically to inactivate bacteria by creating free radicals [43]. The cavitation-produced free radicals could cause the bacterial cells to suffer damage and stop functioning. Since heat may denature and deteriorate bacterial DNA, protein, and other parts of cells, the temperature increase that takes place during TS may also help in the deactivation of bacteria [44].

Compared to the fresh juice samples, the TSSJ juice's YMC was lower (2.84 ± 0.03 log CFU/ml), ranging from to 1.44 ± 0.03 to 2.72 ± 0.02 log CFU/ml. A rise with either amplitude or temperature results in a decrease in the YMC population. This observation implies that elevated temperatures and amplitudes exert a more pronounced effect in reducing yeast and mold counts (YMC). Several factors contribute to the effectiveness of TS with high amplitudes, temperatures, and durations in diminishing yeast and mold counts [43]. The physical effects of bubbling, which can harm cell membranes and result in cell death, are one theory. The generation of radicals without charge, which can cause cellular inflammation and cell damage, is another factor. In addition, a rise in temperature may lead to protein denaturation to occur which might inactivate microorganisms. By combining these effects, treated juice may experience a decrease in the amount of yeast and mold [44]. Alongside TS, more antimicrobial agents or high-pressure

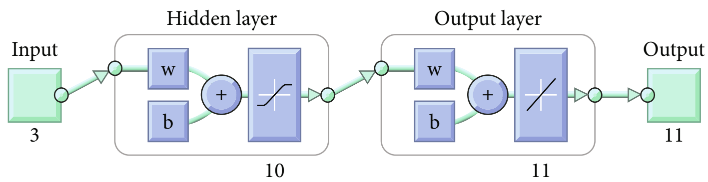

Figure 8: The topology of a well-developed ANN model for TSSJ. Under the input, 3 indicates the independent parameters (temperature, amplitude, and treatment time), while output 11 indicates the dependent parameters (pH, TSS, TA, AA, AOA, TPC, TFC, TVC, and YM). W: weight; b: bias; ANN: artificial neural network; TSSJ: thermosonicated sohshang juice; TSS: total soluble solid; TA: titratable acidity; AA: ascorbic acid; AOA: antioxidant activity; TPC: total phenolic content; TFC: total flavonoid content; TVC: total viable content; YM: yeast and mold count.

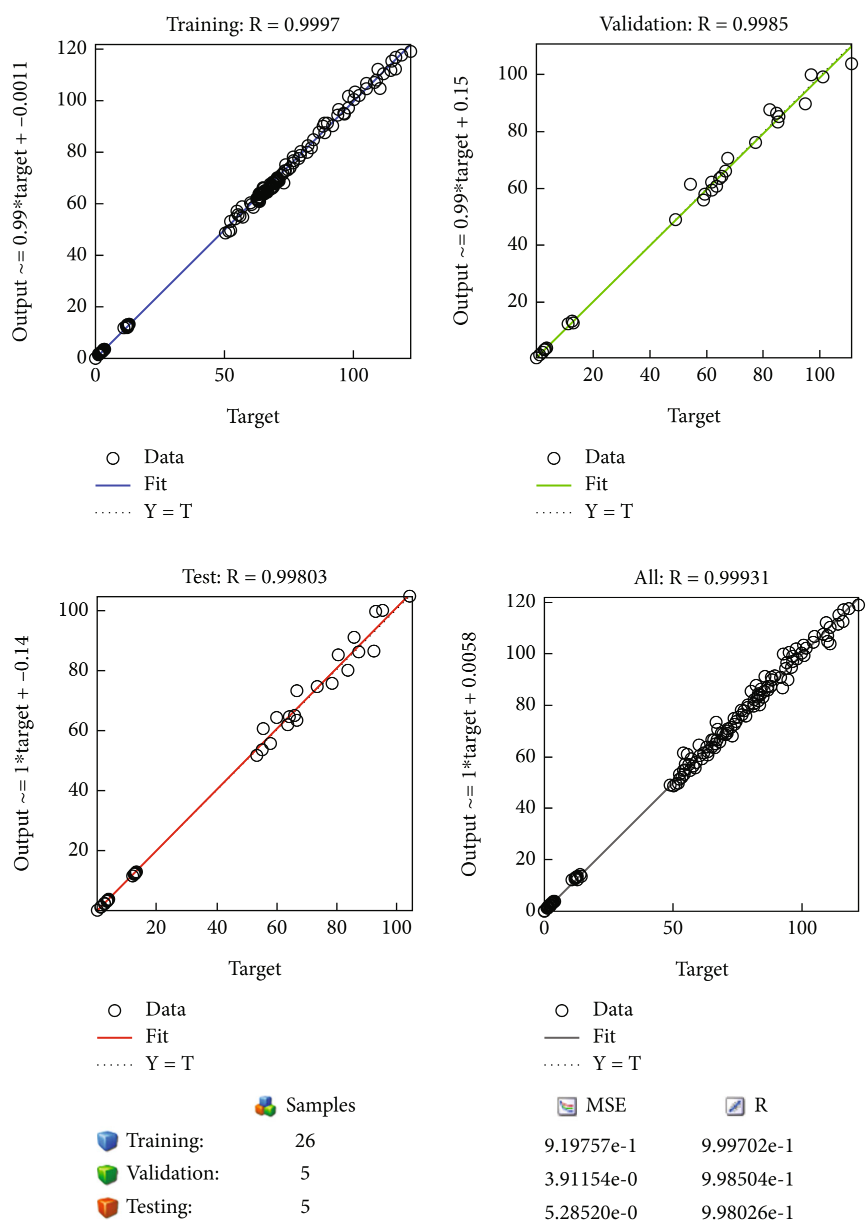

Figure 9: The correlation coefficient (*R*) of training test and all data of well-developed ANN model. ANN: artificial neural network; MSE: mean square error. Output, predicted data generated by the ANN; target, expected outcome for the given input; training, adjustment in internal parameters (weights and biases) based on a labelled data set; testing, accuracy, precision, recall, and mean square error, depending on the type of task (classification or regression); and validation, monitoring and fine-tuning of the model's performance.

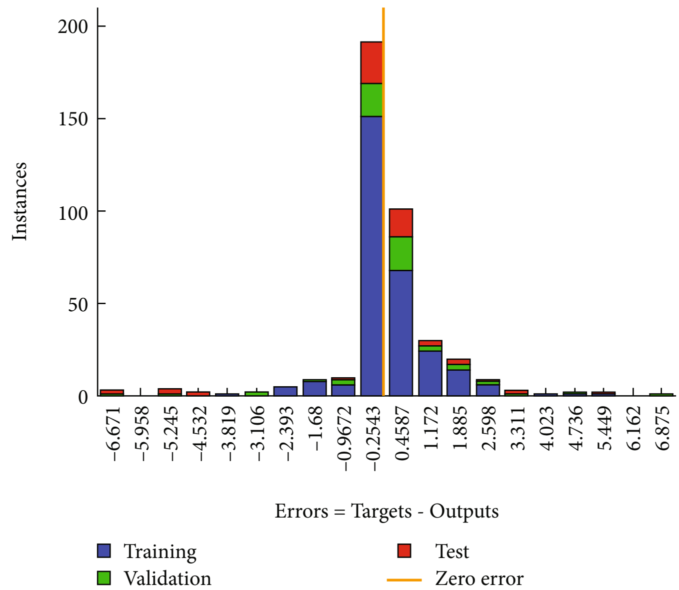

Figure 10: Error histogram of the developed ANN model. ANN: artificial neural network. Instances, the number of data points or examples that fall into different error or loss bins within the histogram; zero error, model's predictions matching the true target values exactly for those instances.

recovery may be needed to produce fluids via the lowest possible level of dietary and sensory degradation.

3.5. Effectiveness and Assessment of the Incorporated ANN Model. As previously reported in studies, a variety of criteria, including MAE, R^2, and error histogram, were used to identify the ideal variables spanning the ANN [28, 44]. A network structure with a concealed layer of ten neural connections was discovered to produce the most effective outcomes after evaluating a number of topologies of the network. Figure 8 shows the framework of the competent ANN algorithm using the ideal topology (3 : 10 : 11), where the neurons' associations and weights within the various layers, in addition to the multiple layers' bias and tumbling point values (both hidden and output), are arranged in an array format. To be more precise, the area of the structure representing the amount of weight associations throughout neural networks in the input layer and concealed layers was 10×3, and the area representing the weight links among the neurons in the concealed and output layers of the model was 10×11. Ultimately, the neural networks' bias/tipping value points in the hidden as well as output layers had a matrix size of 10×1 and 11×1, respectively [45].

The coefficient of variance (R), which was employed to assess the ANN model's performance, was determined to be 0.9997 regarding the training established and 0.99931 for both performance data sets, respectively (Figure 9). The error histogram (Figure 10) was used to calculate the variation among the desired or discovered worth of the result and the subsequent value of the previously determined ANN model. The lowest bar on the graph at zero error indicated how accurate the designed ANN model was. To validate the created ANN model, statistical measures like the degree R^2, MSE, and overall MAE were computed alongside the significance coefficient [28]. The outcomes of the experiment are shown in Table 3, and the MSE, R^2, and MAE values for each response obtained by the implementation of ANN illustrating SJ comprehending by TS are shown in Table 4 [46]. The coefficients of variation (R^2 values) were 0.91 (pH), 0.96 (TSS), 0.94 (TA), 0.92 (CI), 0.98 (BI), 0.96 (AA), 0.90 (AOA), 0.97 (TPC), 0.93 (TFC), 0.96 (TVC), and 0.94 (YMC). The literature indicates that all values are acceptable and satisfactory [45]. R^2 must have a minimum value of 0.80 to be deemed the model with the greatest fit. For every response, the generated ANN model's R^2 values were greater than 0.80, indicating the model's feasibility. Table 4 displays the anticipated outcomes of the inputs derived from the approved ANN model.

As an orientation (70% of the conducted experiments data), approval (15% of the conducted experiments data), and evaluation (15% of the conducted experiments data), each set of the 36 experimental findings was randomly chosen. The method of training was used to determine the parameters of the network, which were validated in order to assess their stability and examined for preventing errors [46]. A model of a neural network comprising triple inputs, ten concealed, and ten layers of output was employed in this investigation (Figure 8). It was required to calculate the total amount of neurons in the layer that is hidden by keeping the network trained up until the minimal MSE and greatest R^2 are reached to create the best ANN model for accordance prediction. The obscured layer's neuron count was adjusted to ten according to the findings, which indicated that a minimum MSE were obtained as 0.82 (pH), 0.46 (TSS), 0.41 (TA), 0.33 (CI), 0.57 (BI), 0.58 (AA), 0.62 (AOA), 0.45 (TPC), 0.45 (TFC), 0.32 (TVC), and 0.41 (YMC) for each of the following: development, evaluation, confirmation, and all data sets, in that order. The training process

Table 3: Experimental outputs for the TS trials[1].

Treatment	pH	TSS	TA	CI	BI	AA	AOA	TPC	TFC	TVC	YM
TSSJ-30-30-15	3.86	12.97	3.27	1.070	0.107	61.76	49.15	82.40	67.55	3.79	2.72
TSSJ-30-30-30	3.81	13.01	3.32	1.083	0.119	62.87	50.45	84.36	70.64	3.68	2.67
TSSJ-30-30-45	3.77	12.75	3.35	1.147	0.149	65.81	51.62	86.53	73.95	3.60	2.59
TSSJ-30-30-60	3.71	10.73	3.38	1.231	0.180	66.78	52.37	88.41	75.34	3.58	2.52
TSSJ-30-40-15	3.83	13.13	3.37	1.117	0.147	63.85	53.39	87.48	73.59	3.55	2.54
TSSJ-30-40-30	3.76	13.03	3.40	1.211	0.170	65.24	54.11	88.59	76.63	3.51	2.48
TSSJ-30-40-45	3.73	12.98	3.42	1.351	0.189	66.73	55.15	92.49	78.67	3.44	2.44
TSSJ-30-40-60	3.70	12.99	3.44	1.401	0.200	67.23	57.00	96.28	81.71	3.41	2.37
TSSJ-30-50-15	3.80	11.24	3.43	1.299	0.173	63.61	58.89	94.78	77.37	3.37	2.47
TSSJ-30-50-30	3.70	12.50	3.46	1.432	0.206	60.51	60.35	96.49	79.30	3.32	2.42
TSSJ-30-50-45	3.66	12.03	3.49	1.489	0.216	60.31	63.37	97.89	83.63	3.28	2.38
TSSJ-30-50-60	3.64	11.35	3.52	1.536	0.224	54.35	64.61	101.04	85.60	3.25	2.28
TSSJ-40-30-15	3.80	11.50	3.34	1.350	0.151	63.24	52.66	86.59	73.74	3.54	2.63
TSSJ-40-30-30	3.77	12.14	3.36	1.396	0.179	64.04	55.31	89.85	76.83	3.47	2.50
TSSJ-40-30-45	3.69	12.63	3.39	1.413	0.187	65.87	56.30	91.80	78.63	3.42	2.44
TSSJ-40-30-60	3.62	13.01	3.41	1.423	0.196	66.02	57.85	95.39	83.83	3.32	2.37
TSSJ-40-40-15	3.79	12.45	3.43	1.389	0.180	65.06	54.86	93.89	76.74	3.44	2.47
TSSJ-40-40-30	3.72	12.63	3.46	1.442	0.192	67.75	56.96	96.95	79.44	3.39	2.42
TSSJ-40-40-45	3.68	12.52	3.48	1.477	0.198	69.15	63.13	98.13	82.26	3.33	2.38
TSSJ-40-40-60	3.62	12.97	3.51	1.544	0.213	66.89	64.35	104.41	85.91	3.25	2.30
TSSJ-40-50-15	3.69	11.32	3.54	1.595	0.202	66.75	65.50	96.93	84.76	3.32	2.36
TSSJ-40-50-30	3.67	11.59	3.57	1.617	0.223	65.22	67.23	98.00	86.61	3.24	2.27
TSSJ-40-50-45	3.63	13.00	3.63	1.622	0.244	64.26	68.79	105.44	88.52	3.19	2.23
TSSJ-40-50-60	3.61	13.01	3.68	1.622	0.256	63.79	69.95	110.22	91.97	3.13	2.17
TSSJ-50-30-15	3.77	12.53	3.41	1.513	0.182	60.15	55.56	93.12	80.65	3.42	2.43
TSSJ-50-30-30	3.70	12.87	3.44	1.560	0.203	61.33	57.62	100.61	82.74	3.27	2.35
TSSJ-50-30-45	3.63	12.70	3.47	1.575	0.212	61.95	59.55	111.14	85.18	3.04	2.26
TSSJ-50-30-60	3.57	13.34	3.51	1.619	0.217	62.44	61.19	122.03	91.68	2.90	2.16
TSSJ-50-40-15	3.66	11.02	3.56	1.410	0.206	65.77	66.30	105.16	94.30	3.15	2.25
TSSJ-50-40-30	3.60	12.67	3.63	1.557	0.211	66.98	72.93	109.04	100.11	2.87	2.14
TSSJ-50-40-45	3.58	12.99	3.73	1.581	0.222	68.64	70.24	111.40	108.12	2.54	2.05
TSSJ-50-40-60	3.53	12.69	3.80	1.597	0.229	67.55	71.70	114.18	116.14	2.22	1.84
TSSJ-50-50-15	3.61	13.01	3.72	1.644	0.220	65.49	70.49	109.69	102.03	2.45	1.74
TSSJ-50-50-30	3.55	12.99	3.75	1.664	0.252	63.74	69.61	114.69	104.41	2.13	1.63
TSSJ-50-50-45	3.53	12.93	3.76	1.676	0.267	55.33	69.96	118.43	105.06	1.96	1.56
TSSJ-50-50-60	3.53	13.04	3.74	1.676	0.272	54.64	71.04	116.36	107.85	1.43	1.44

[1]TSSJ (thermosonicated sohshang juice) 30, 40, and 50%; temperature 30, 40, and 50°C; and treatment time 15, 30, 45, and 60 min. TSS: total soluble solid; TA: titratable acidity; CI: cloudiness; BI: browning index; AA: ascorbic acid; AOA: antioxidant activity; TPC: total phenolic content; TFC: total flavonoid content; YM: yeast and mold count; TS: thermosonication.

efficiency of the ANN conceptual an erroneous histogram and a regression analysis are displayed in Figures 9 and 10. Figure 11 shows the MSE effectiveness as an indicator of the total amount of epochs for testing, validation, and training data. The graph demonstrates that as the variety of epochs rises, the network's efficiency improves; at five epochs, authorization accomplishment was at its best with an MSE perusing of 3.0373.

The fallacious value histogram has an error value of -0.2543 (Figure 11), suggesting that the algorithm does a good job of forecasting the desired values. The regression test results are shown in Figure 11, wherein all data sets exhibit a statistically significant correlation between the expected outcomes and the actual target values. As can be seen in Tables 3 and 4, there is an excellent agreement among the actual and projected values. The expected values of the inputs that come from the ANN model are shown in Table 4. The reliability of the model is supported by the significant relationship between the real and projected values. The fact that this model performed well shows how valuable it could be as a means of predicting for upcoming experiments. The ANN model can be used to foresee the reaction

Table 4: Predicted network outputs from ANN modelling[1].

Treatment	PH	TSS	TA	CI	BI	AA	AOA	TPC	TFC	TVC	YM
TSSJ-30-30-15	3.77	12.98	3.36	1.167	0.197	62.31	49.26	82.95	67.32	3.78	2.55
TSSJ-30-30-30	3.77	13.12	3.32	1.146	0.205	62.03	47.60	85.07	65.86	3.82	2.47
TSSJ 30-30-45	3.75	12.34	3.33	1.227	0.146	66.55	52.11	87.17	73.30	3.61	2.48
TSSJ-30-30-60	3.74	12.18	3.34	1.246	0.134	67.49	53.70	88.03	76.12	3.54	2.49
TSSJ-30-40-15	3.79	12.70	3.30	1.060	0.181	58.10	50.21	92.75	75.85	3.46	2.41
TSSJ-30-40-30	3.71	12.72	3.43	1.230	0.190	64.11	55.41	88.10	76.63	3.57	2.57
TSSJ-30-40-45	3.72	12.44	3.38	1.268	0.153	66.17	55.07	92.58	79.17	3.47	2.47
TSSJ-30-40-60	3.72	12.43	3.36	1.283	0.145	66.30	55.18	96.10	81.30	3.40	2.42
TSSJ-30-50-15	3.84	11.78	3.43	1.363	0.169	62.46	58.71	93.75	78.01	3.43	2.55
TSSJ-30-50-30	3.82	11.94	3.42	1.396	0.174	62.22	59.36	97.84	79.20	3.38	2.49
TSSJ-30-50-45	3.75	12.68	3.41	1.536	0.220	63.32	56.35	100.23	64.86	3.76	2.43
TSSJ-30-50-60	3.68	13.07	3.34	1.589	0.230	64.08	54.74	104.20	58.84	3.85	2.27
TSSJ-40-30-15	3.78	12.15	3.38	1.287	0.127	63.27	52.80	85.88	74.26	3.55	2.60
TSSJ-40-30-30	3.78	12.32	3.41	1.323	0.128	64.97	54.42	89.78	76.87	3.46	2.56
TSSJ-40-30-45	3.77	12.43	3.42	1.342	0.132	65.07	55.17	92.69	78.63	3.41	2.53
TSSJ-40-30-60	3.74	12.31	3.45	1.386	0.124	66.31	58.15	95.50	83.55	3.29	2.52
TSSJ-40-40-15	3.87	11.77	3.41	1.509	0.114	66.01	58.56	96.47	81.10	3.29	2.47
TSSJ-40-40-30	3.77	12.54	3.46	1.578	0.163	67.26	59.11	96.97	78.98	3.41	2.45
TSSJ-40-40-45	3.64	12.72	3.47	1.590	0.172	68.81	62.79	98.67	82.18	3.28	2.32
TSSJ-40-40-60	3.55	13.25	3.48	1.556	0.212	67.17	64.22	104.45	85.80	3.19	2.21
TSSJ-40-50-15	3.67	11.63	3.54	1.491	0.206	66.23	65.38	96.57	84.79	3.00	2.05
TSSJ-40-50-30	3.60	11.75	3.63	1.506	0.224	66.28	70.30	102.82	95.52	2.79	2.07
TSSJ-40-50-45	3.53	12.90	3.73	1.588	0.322	64.75	69.30	105.54	88.53	3.15	2.19
TSSJ-40-50-60	3.51	13.24	3.75	1.581	0.343	63.53	69.54	110.14	91.91	3.09	2.16
TSSJ-50-30-15	3.76	12.19	3.36	1.496	0.157	60.31	55.78	92.81	80.62	3.43	2.47
TSSJ-50-30-30	3.70	12.68	3.38	1.525	0.170	61.06	57.34	101.37	82.51	3.31	2.33
TSSJ-50-30-45	3.64	13.23	3.41	1.566	0.183	62.98	59.58	111.06	84.98	3.16	2.18
TSSJ-50-30-60	3.61	13.54	3.45	1.586	0.190	62.60	61.57	121.13	92.15	2.96	2.11
TSSJ-50-40-15	3.63	12.22	3.62	1.560	0.225	65.36	66.87	105.44	94.16	2.88	2.09
TSSJ-50-40-30	3.57	12.65	3.68	1.595	0.241	67.43	68.98	108.00	100.63	2.78	2.09
TSSJ-50-40-45	3.55	12.71	3.70	1.578	0.234	67.86	70.68	111.47	108.77	2.58	2.04
TSSJ-50-40-60	3.53	12.65	3.73	1.588	0.223	68.36	72.90	114.60	115.09	2.43	2.03
TSSJ-50-50-15	3.60	11.82	3.66	1.498	0.222	63.88	70.70	114.18	104.77	2.46	1.88
TSSJ-50-50-30	3.59	11.99	3.68	1.524	0.235	63.80	70.72	115.01	103.84	2.51	1.91
TSSJ-50-50-45	3.54	12.42	3.79	1.675	0.280	66.12	72.20	112.06	96.86	2.83	2.10
TSSJ-50-50-60	3.50	11.93	3.87	1.738	0.250	69.53	77.67	111.14	104.45	2.65	2.18
R^2	0.913	0.964	0.941	0.924	0.986	0.963	0.976	0.945	0.939	0.965	0.943
MSE	0.826	0.468	0.416	0.338	0.579	0.581	0.625	0.456	0.457	0.324	0.416
MAE	0.001	0.024	0.008	0.004	0.005	-0.917	0.197	-0.343	1.225	-0.077	-0.023

[1]TSSJ (thermosonicated sohshang juice) 30, 40, and 50%; temperature 30, 40, and 50°C; and treatment time 15, 30, 45, and 60 min. ANN: artificial neural network; TSS: total soluble solid; TA: titratable acidity; CI: cloudiness; BI: browning index; AA: ascorbic acid; AOA: antioxidant activity; TPC: total phenolic content; TFC: total flavonoid content; TVC: total viable content; YM: yeast and mold count; *R*: coefficient of determination; MSE: mean square error; MAE: mean absolute error.

for a given set of input variables, which can save time and resources when conducting experiments. The reliability of the information and the accuracy of the experiment's conclusions are further strengthened by the substantial correlation between the actual and projected values. Even though the outcomes of the ANN model are promising, it is important to remember that more data from experiments will need to be utilized for validating the model. This could help to further improve the precision and reliability of the model. Overall, the ANN model's efficacy in predicting response is

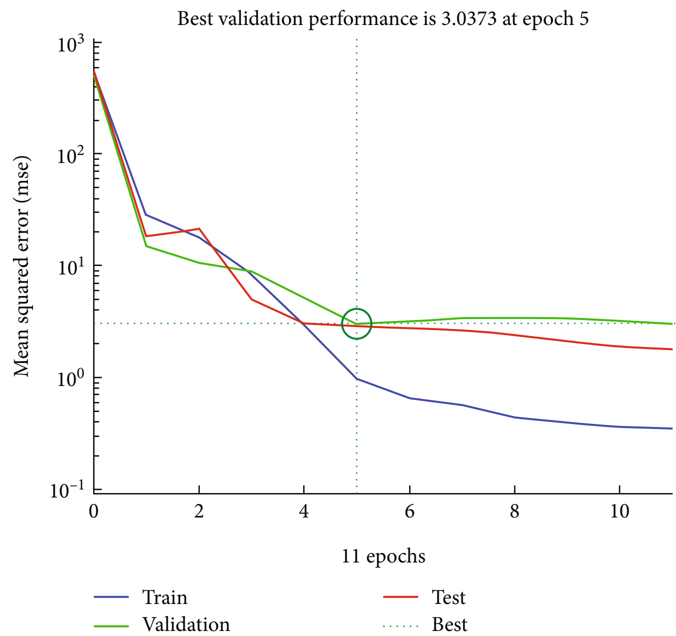

Figure 11: The performance of MSE with respect to the increase in the number of the epochs. MSE: mean square error. Epochs: the number of epochs is a hyperparameter that needs to be set by the user. Epochs: number of time iterations of the entire training data set. The green circle represents the context of an ANN's MSE performance, indicating that a specific data point is converging to a desired value.

a good step forward for the food processing sector and could lead to the development of improved and more effective approaches to processing [28, 44, 46, 47].

3.6. Neural Network-Driven Process Parameter Optimization. ANN is a popular method that optimizes nonlinear and near-linear problems by using different functions like crossover, choices, and modification to population entities [28, 47, 48]. After 19 iterations, the following list of the best circumstances for analyzing SJ with TS using ANN is provided: at treatment condition (amplitude: X1, temperature: X2, and time: X3) 1 (40% X1, 40°C X2, and 45 min X3), 2 (50% X1, 40°C X2, and 30 min X3), 3 (50% X1, 30°C X2, and 60 min X3), 4 (50% X1, 40°C X2, and 60 min X3), and 5 (50% X1, 50°C X2, and 60 min X3). Through ANN modelling, the optimal treatment combination yielded the highest and most desired values for the physical and chemical properties, functioning, and biological attributes. These results demonstrated a good match with the expected values, demonstrating the accuracy and growth potential of the ANN model [28, 49, 50].

4. Conclusions

The present research optimized and modelled ultrasound-assisted SJ extraction using a multiple-layered ANN. The effect of TS on various responses, at various levels of X1, X2, and X3 (pH, TSS, TA, CI, and BI), on including nutritional, microbiological, and physicochemical properties was also ascertained. The established artificial neural network (ANN) demonstrates high *R* values across validation, testing, training, and all data sets. This indicates a significant agreement between the experimented and anticipated values, as evidenced by low mean square error, on all dependent variables. Using an established ANN, the following variables have been found to be the best extraction variables: following 19 iterations, the ideal conditions for processing SJ by sonication have been determined through ANN. The maximum improvement in quality attributes resulting from thermosonication of sohshang juice was achieved under the ideal treatment condition of 50% amplitude and 40°C for 60 minutes. The obtained anticipated results from the developed ANN model closely matched the real outcomes at the method's variables that had been optimized. The results suggest that TS could be a fascinating substitute for thermal pasteurization for the preservation of SJ, reducing or preventing quality deterioration, and enhancing functional attributes. ANNs can contribute to optimizing maintenance schedules by analyzing historical data to predict equipment failures. This helps in scheduling maintenance activities at optimal times, minimizing downtime, and maximizing equipment lifespan.

Abbreviations

CI: Cloudiness
TA: Titratable acidity
BI: Browning index
TSS: Total soluble solids
AOA: Antioxidant activity
AA: Ascorbic acid
TFC: Total flavonoid content
R: Coefficient of determination
TVC: Total viable counts
TPC: Total phenolic content
MAE: Mean absolute error
YMC: Yeast and mold count

PS: Pasteurization
MSE: Mean square error
TS: Thermosonication
ND: Not detected
TSSJ: Thermosonicated sohshang juice
RSJ: Raw sohshang juice
ANN: Artificial neural networks
GAE: Gallic acid equivalents
SJ: Sohshang juice
X1: Amplitude
PSSJ: Pasteurized sohshang juice
X2: Sonication temperature
QE: Quercetin equivalent
X3: Sonication time
CFU: Colony forming unit.

Data Availability

All data generated or analyzed during this study are included in the manuscript.

Conflicts of Interest

The authors declare no conflicts of interest.

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