Technological Optimization of Thermal Processing for Semi-Preserved Sun-Dried Tomatoes: Balancing Microbial Safety and Quality

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Abstract: Thermal processing is essential for ensuring the safety and shelf stability of semi-preserved foods, yet it often compromises product quality. This study investigated the impact of three thermal schedules on semi-preserved sun-dried tomatoes in olive oil: pasteurization (E1: 90 °C/60 min), mild sterilization (E2: 110 °C/40 min), and high sterilization (E3: 115 °C/25 min). The effects on microbiological safety, physicochemical properties-including color, total phenolic content, antioxidant activity, and oxidative stability-and sensory quality were evaluated. Results showed that increasing thermal intensity significantly improved microbial inactivation, with total mesophilic aerobic counts decreasing from 1.37×10^3 CFU/g for E1 to 1.6×10^2 CFU/g for E3. However, stronger treatments caused substantial quality losses, including color darkening (L* value decreased from 25.40 to 18.89), a dramatic reduction in total phenolic content (up to 73.79% for E3), and decreased antioxidant activity and oxidative stability. Sensory evaluation clearly favored E1, which scored highest for color, aroma, and texture. Although the mild 90 °C treatment best preserves organoleptic and nutritional qualities, its low sterilizing value (F_0 = 0.046 min) necessitates strict cold-chain management. These findings emphasize the need to balance safety and quality when selecting thermal processing conditions for semi-preserved products.

1 INTRODUCTION

The food industry widely employs thermal processing to ensure the microbiological safety of food products and extend their shelf life. Among these products, semi-preserved items like sun-dried tomatoes in olive oil hold a significant market position. While valued for their taste, their often near-neutral pH makes them susceptible to the growth of pathogenic and spoilage microorganisms, most notably *Clostridium botulinum* [1]. The application of an appropriate thermal treatment is therefore an essential processing step. However, an intense thermal process, while microbiologically effective, can lead to undesirable degradation of the product's nutritional and sensory qualities [2]. Heat can destroy thermosensitive compounds such as vitamins and polyphenols (known for their antioxidant activity) and can alter natural pigments (lycopene), texture, and aroma [3]. Consequently, there is a significant challenge in defining an optimal thermal schedule that strikes the best compromise between microbial destruction and the preservation of product quality attributes [4].

This study aims to evaluate the impact of three thermal processing schedules (pasteurization, mild sterilization, and high sterilization) on the overall quality of semi-preserved sun-dried tomatoes in olive oil. The efficacy of each treatment was measured by calculating the sterilizing value (F_0) and conducting microbiological analyses, while the impact on quality was assessed through physicochemical analyses (color, phenolics, antioxidant activity, oxidative stability) and a comprehensive sensory evaluation.

2 MATERIAL AND METHODS

2.1 Preparation of the Samples

Sun-dried tomatoes (80 g) were manually packed into clean glass jars with 1.6 g of salt (2% w/w). Olive oil (190 mL) was added to completely immerse the tomatoes. The jars were sealed without overtightening the lids before being subjected to thermal treatment in an autoclave (Fig. 1).

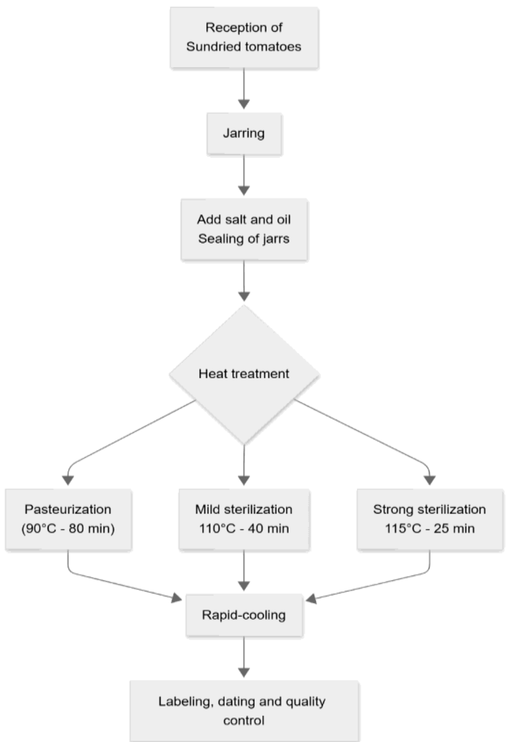

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Figure 1: Production process diagram of semi preseved/Sterilized sun-dried tomatoes in olive oil.

2.2 Thernal Treatment and F_0 Values Calculation

3 thermal schedules were applied: E1, pasteurization at 90 °C for 60 minutes; E2, mild sterilization at 110 °C for 40 minutes; and E3, high sterilization at 115 °C for 25 minutes. The sterilizing value (F_0), which quantifies the microbial inactivation efficiency of the treatment, was calculated for each schedule using the folling formula [5]:

$$F_0 = t \times 10^{((T-121.1)/z).}$$

Where:

- t = processing time (min);
- T = temperature (°C);
- z = 10°C (standard value for *Clostridium botulinum*).

2.3 Determination of Total Mesophilic Aerobic Count (TMAC)

In accordance with the NF V 08-051 standard [6], 1 g of each sample was serially diluted in buffered peptone water. A volume of 1 mL from each dilution was surface-plated onto Plate Count Agar (PCA). After incubation at 30°C for 72 hours, colonies were counted. Results were expressed as colony-forming units per gram (CFU/g).

2.4 Physicochemical Analyses

2.4.1 Color Parameters Evaluation

Color was measured using a Techkon SpectroDens colorimeter. The CIELAB coordinates L* (lightness), a* (red-green axis), and b* (yellow-blue axis) were determined from the average of three readings per sample.

2.4.2 Extraction and Determination of Total Phenolic Content (TPC)

3 g of ground sample was macerated in 30 ml of ethanol/water (80% v/v) for 24 hours, followed by sonication (15 min) and centrifugation (5000 rpm, 10 min). the supernatant was analyzed using the folin-ciocalteu method [7]. Absorbance was read at 765 nm, and results were expressed as mg of gallic acid equivalent per 100 g of sample (mg GAE/100 g).

2.4.3 Antioxidant Activity

Antioxidant activity was determined using the DPPH assay [8]. A 100 mM solution of DPPH in methanol was prepared, and 1 mL of this solution was mixed with 200 µL of the extract. The mixture was shaken vigorously and kept in the dark at room temperature for 20 min. The absorbance of the resulting solution was measured at 517 nm.

The antioxidant activity (%) was calculated as:

$$\text{Antioxidant activity (\%)} = (1\text{-}As/A_0) \times 100,$$

where A_0 is the absorbance of the control at 517 nm, and As is the absorbance of the sample. Absorbance was measured at 517 nm, and results were expressed as IC_{50}.

2.4.4 Rancimat

The oxidative stability of the oil was evaluated at 121°C with an air flow rate of 20 L/h. The induction time (in hours), which marks the onset of accelerated oxidation, was measured using a Rancimat device.

2.3 Sensory Analysis

Sensory analysis was performed on sun-dried tomatoes in olive oil (E1, E2, E3) using an untrained panel of 60 participants. Samples were randomly coded (Treatment A, B, C) to prevent bias. Panelists evaluated aroma, taste, color, texture, and overall acceptability using a 5-point scale (Very pleasant, Pleasant, Slightly pleasant, Unpleasant, Very unpleasant). To minimize sensory fatigue, water was provided to rinse the palate between samples. Purchase intention was also assessed on a 5-point scale (Definitely buy to Definitely not buy), and participant comments were collected for additional qualitative analysis.

3 RESULTS AND DISCUSSION

3.1 Sterilizing Value (F_0) and Microbiological Analysis

The calculated F_0 values and total mesophilic aerobic counts (TMAC) are presented in Table 1. The efficacy of the thermal treatment increased with temperature.

Table 1: F_0 values and TMAC for samples under different thermal schedules.

Sample	Treatment	F_0 (min)	TMAC (CFU/g)
E1	90°C / 60 min	0.046	1.37 x 10^3
E2	110°C / 40 min	3.08	8.2 x 10^2
E3	115°C / 25 min	6.1	1.6 x 10^2

E1 (pasteurization) exhibited a very low F_0 value (0.046 min), corresponding to a bacterial load of 1.37 × 10^3 CFU/g, slightly above the Codex Alimentarius limit for pasteurized products (10^3 CFU/g). This treatment is insufficient to eliminate all vegetative cells and does not affect bacterial spores, thus requiring refrigerated storage Sample E2 reached an F_0 of 3.08 min, exceeding the 3 min threshold recommended for commercial sterilization, reducing the microbial load to 8.2 × 10^2 CFU/g. Sample E3, with an F_0 of 6.1 min, achieved the highest microbiological safety (1.6 × 10^2 CFU/g), meeting the recommended F_0 > 5 min for low-acid foods [9]. While E2 and E3 provide superior stability, their more intense thermal treatments have notable effects on product quality, which must be carefully considered when selecting an optimal processing strategy.

3.2 Impact on Color Parameters

According to results, Thermal processing significantly altered the color of the tomatoes (Table 2).

Table 2: Color parameters of the samples.

Sample	L*	a*	b*
Sun-dried tomato	31.84 ± 0.52	16.94 ± 0.48	13.38 ± 0.35
E1	25.40 ± 0.47	5.77 ± 0.41	7.71 ± 0.29
E2	19.01 ± 0.39	-3.58 ± 0.36	1.44 ± 0.27
E3	18.89 ± 0.12	-3.79 ± 0.18	-0.59 ± 0.15

Lightness (L*) decreased with increasing temperature, indicating darkening due to Maillard reactions and caramelization. The a* (redness) and b* (yellowness) values dropped dramatically, even shifting to negative (greenish) values for E2 and E3.

This reflects severe degradation of natural pigments, particularly lycopene, which is known to be sensitive to temperatures above 100°C [10]. The E1 treatment better preserved the characteristic reddish-orange color of the product.

3.3 Total Phenolic Content and Antioxidant Activity.

The intensity of the thermal treatment had a direct negative impact on the phenolic compound content and antioxidant activity (Table 3).

Untreated tomatoes are rich in phenolics (12.02 mg GAE/100 g). The E1 treatment caused a substantial loss of 40.74%, which intensified sharply with E2 (66.62%) and E3 (73.79%). This degradation is attributed to the thermal instability of phenolic compounds [11]. Antioxidant activity declined accordingly, as shown by increasing IC_{50}.

E1 was already significantly less active than the control, and E3 exhibited the weakest activity. This loss is directly correlated with the degradation of phenolics, which are major contributors to the antioxidant capacity of plant-based foods.

Table 3: Total Phenolic Content (TPC) and antioxidant activity (IC_{50}).

Sample	TPC (mg GAE/100 g)	Phenolic Loss (%)	IC_{50} DPPH (mg/mL)
Sun-dried tomato (Control)	12.02 ± 0.8	-	1.12 ± 0.5
E1 (90°C)	7.12 ± 0.98	40.74%	3.85 ± 0.91
E2 (110°C)	4.01 ± 0.77	66.62%	8.12 ± 1.10
E3 (115 °C)	3.15 ± 0.34	73.79%	12.24 ± 1.25

3.4 Oxidative Stability

The oxidative stability of the oil, measured by the Rancimat induction time, also decreased with the intensity of the treatment (Table 4).

Table 4: Induction time of semi-preserved tomato samples.

Sample	Induction Time (h)
E1 (90°C)	1.89
E2 (110°C)	1.71
E3 (115°C)	1.32

A longer induction time indicates greater resistance to oxidation. The E1 treatment showed the best stability (1.89 h), while E3 was the most susceptible to oxidation (1.32 h). Heat degrades natural antioxidants, such as polyphenols from the tomatoes and tocopherols from the olive oil, that protect lipids from oxidation. A more severe treatment thus accelerates the future degradation of the product [12].

3.5 Sensory Analysis and Purchase Intent

The sensory analysis confirmed the organoleptic superiority of the least intense treatment (Fig. 2).

Sample E1 (90°C) was overwhelmingly preferred across all criteria: color, aroma, taste, and texture. Panelists appreciated its brighter color, fresher aroma, and firm-yet-tender texture. Conversely, samples E2 and E3 were rated as less appealing. Their darker color, "cooked" aroma, and overly soft texture were penalized. These results are consistent with the physicochemical analyses: the degradation of pigments, volatile aromatic compounds, and cellular structure at high temperatures explains this negative perception.

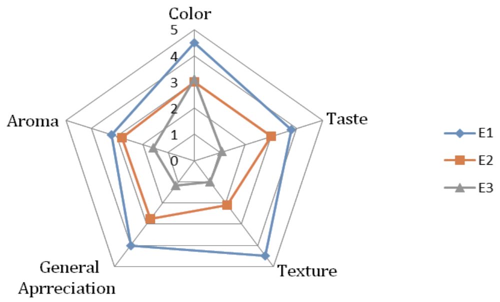

Figure 2: Sensory profile of the samples as evaluated by the consumer panel.

Overall, the concept of semi-preserved sun-dried tomatoes was well-received, with over 73% expressing favorable purchase intent. However, the strong sensory preference for E1 highlights the central dilemma: the treatment most liked by consumers is also the least safe microbiologically. This finding underscores the critical importance of maintaining an unbroken cold chain for a product like E1 and the need to clearly communicate this requirement to the consumer.

4 CONCLUSIONS

This study highlights the impact of thermal processing on the balance between safety and quality in semi-preserved sun-dried tomatoes in olive oil. Intense treatments (110–115 °C) achieve high microbial inactivation and an adequate F_0 but cause significant color degradation, loss of polyphenols and antioxidants, and reduced sensory appeal. Mild pasteurization (90 °C, 60 min) preserves color, aroma, texture, and antioxidants, yielding a product with high sensory quality, though its limited F_0 (0.046 min) requires strict refrigerated storage. Optimal process selection depends on commercial strategy: E2 (110 °C, 40 min) suits ambient-stable products with potential sensory optimization, while E1 is ideal for premium refrigerated products. The study underscores the value of integrating F_0 modeling, microbiological, physicochemical, and sensory analyses to optimize safety, quality, and consumer satisfaction.

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