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Optimizing confectionery production: A semi-automatic gummy jelly dropping machine design and performance evaluation

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Abstract: Confectionery products, particularly popular among individuals under 17, include treats such as jellies and gummies. Traditionally, the manual process of dropping gummy jelly into molds, one piece at a time, is labor-intensive and time-consuming. This method is susceptible to the gummy jelly's physical properties, which can coagulate when exposed to air below its melting point. This study presents the development of a semi-automatic gummy jelly dropping machine to streamline the handmade confectionery production process. The machine, fabricated from stainless steel with dimensions of 36.00 centimeters (width) x 56.00 centimeters (height) x 47.00 centimeters (length), utilizes an aluminum piston mechanism (34 millimeters diameter and 142 millimeters length) for controlled gummy jelly dispensing. A 950-watt heater warms the liquid gummy jelly in a basin located at the piston's back, with tests conducted at temperatures of 80, 100, and 120 degrees Celsius. Results indicate that the optimal temperature for the semi-automatic gummy jelly dropping machine is 120 degrees Celsius, achieving an average dispensing time of 99.35 seconds. The machine's production capacity is 36.66 kilograms per hour, with a maximum efficacy of 73.75 percent. The produced gummy jelly exhibits a moisture content of 12.07 percent, lightness (L) of 52.63±4.67.63, red/green (a*) of 0.27±0.11, and yellow/blue (b*) of 4.08±3.13. Its hardness measures 1027.75 grams, its gumminess is 916.25 grams, and its water activity (aw) is 0.80. The study is significant since it verifies that there is no microbial development.

Keywords: *Confectionery production, Food processing equipment, Gummy jelly, Optimal temperature, Productivity enhancement, Semi-automatic gummy jelly machine.*

1. Introduction

Confectionery products have widespread appeal among various age groups, notably drawing the attention of individuals under 17, especially towards treats like jellies and gummies. These confections feature an organic, chewy composition, comprising at least 45% fruits and approximately 55% sugars, typically in the form of sucrose syrup or glucose.

Their formulation involves a fusion of gelling agents, acids, aromas, and food colorants, creating their distinctive gel-like structure [1-4].

Gummy jelly, a widely popular snack, stands out for its delightful chewiness and softness, frequently providing a sweet or sour taste experience. Its essential constituents encompass fruit juice, sugar, acids, and various gelling agents [5].

Hydrocolloids are a group of commonly used gelling agents that include gelatin, sodium alginate, pectin, carrageenan, methylcellulose, sodium carboxymethyl cellulose, and modified starch, among others. The specific types and quantities of gelling agents significantly influence the gel's structure, thereby impacting the texture and resulting attributes of gummy jelly products [5]. Research indicates

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the widespread use of gelatin as a favored gelling agent due to its capacity to bestow a soft, chewy texture upon gummy jellies while also providing flexibility and a transparent appearance [6-8]. Moreover, commercially available gummy jelly products frequently utilize sodium alginate as a primary gelling agent.

Sodium alginate stands out for creating a thermo irreversible gel, ensuring that products containing it maintain their shape and texture even under heat exposure, thereby preventing deformation [9].

The crafting of gummy jelly, a cherished confection, entails a meticulous process. This process involves the amalgamation of fruit or herbal juice, sweeteners, and crucial gelling agents like gelatin and carrageenan, which play a pivotal role in defining the product's texture and structure [10-13]. This detailed craftsmanship results in a confection possessing a distinctively sticky yet dry texture, which is vital for extending its shelf life [14, 15].

The production of gummy jelly involves several steps, starting with the drying of corn starch at 60 degrees Celsius for four hours [16]. The dried starch is then shaped into molds to create the desired gummy shapes.

The recipe for gummy jelly typically includes sweeteners, gelling agents, fruit juice, food coloring, and various flavors, mixed together to form a uniform paste, which is then heated until it reaches the desired thickness and stickiness.

The mixture is then carefully dropped into molds, and the gummy jelly is left to cool for around 12 to 24 hours. Traditionally, the process of dropping gummy jelly into molds is done manually, one piece at a time. The physical characteristics of gummy jelly, which can coagulate when exposed to air at temperatures below its melting point, have an impact on this time-consuming and labor-intensive method.

Sumrit, et al. [16] attempted to address this issue by designing and building a prototype gummy jelly dispenser to improve efficiency compared to the manual method. The results were promising, with an 83.33 percent increase in work efficiency, reducing the average time required from 16.08 minutes to 2.69 minutes.

However, the prototype machine faced challenges as the temperature of the liquid gummy jelly dropped rapidly during the process. The rapid cooling of the liquid gummy jelly led to clumping and clogging of the dropper holes, hindering continuous production.

To overcome these challenges, this research aims to develop and evaluate the performance of a semi-automatic gummy jelly dropping machine. The proposed solution involves the installation of a heater to maintain the gummy jelly's temperature, preventing it from coagulating and clogging the dropper hole mechanism.

This innovation promises to enable continuous operation, shorten the time required to drop gummy jelly, and improve the consistency and capacity of gummy jelly production.

2. Literature Review

The confectionery industry operates in a dynamic environment that constantly seeks innovation to enhance production efficiency while ensuring product quality. A crucial aspect of this evolution involves the development and optimization of machinery, particularly the design and evaluation of semi-automatic gummy jelly dropping machines. Such advancements significantly impact production rates and the consistency of the final product.

Dai [17] highlighted the challenges within the confectionery industry related to packaging, often carried out manually, leading to issues like waste, injuries, and hygiene concerns. Automation of packaging processes is crucial to reducing these problems, particularly given the industry's frequent changeovers due to the wide variety of products manufactured. Reconfigurable mechanisms and flexible packaging automation systems have been explored, indicating potential solutions to address these challenges.

In recent years, the integration of cutting-edge technologies like artificial intelligence (AI) and machine learning (ML) has revolutionized the food processing industry. Addanki, et al. [18] study highlighted the pivotal role of AI and ML in addressing the demands for improved food quality, nutritional value, and processing methods.

The review emphasized the interdisciplinary nature of AI's application, showcasing its potential to enhance performance across various segments of the food sector. Furthermore, the study emphasized the role of robotics in streamlining processes within the food and beverage industries.

Studies conducted by Kaewsorn, et al. [19] and Onmankhong, et al. [20] focused on evaluating the textural qualities of food products, such as cooked rice, showcasing the importance of processing parameters in influencing physical and chemical properties. These studies underscored the profound impact of soaking, steaming, and incubation durations on the texture and overall quality of food items.

The agro-processing industry has also witnessed significant innovations aimed at improving efficiency and addressing labor-intensive processes. Msuya [21] addressed the inefficiencies and safety hazards of traditional vegetable slicing methods.

The study presented the design and testing of a vegetable slicing machine, aiming to improve efficiency, hygiene, and the drying process for vegetables, thereby enabling better preservation and storage for future use. Similarly, Esenamunjor, et al. [22] focused on cassava processing, designing and evaluating a cassava peeling machine to mitigate labor-intensive tasks and enhance processing efficiency. The machine's performance metrics, including peeling efficiency and throughput capacity, demonstrated significant improvements in cassava processing.

Moreover, advancements in food processing machinery encompass a wide array of innovations tailored to different food items and processing requirements. Studies such as Mizar, et al. [23] contributed to the development of a multi-intake food cutting machine, showcasing its capacity and efficiency in cutting various food materials simultaneously.

The machine's ability to produce uniform cuts at a high capacity proved advantageous for small and medium food enterprises. Moreover, Mahamude, et al. [24] concentrated on designing an intelligent mixer machine for specific food applications, with a focus on enhancing food processing efficiency and functionality.

In the context of small-scale food processing industries, Sonawane, et al. [25] and Tanwar, et al. [26] presented studies on the development and performance evaluation of power-operated slicers for bananas and multipurpose vegetable slicers, respectively. These machines aimed to increase efficiency, reduce manual labor, and minimize waste in processing various food products.

Moreover, innovations tailored to specific processes within the confectionery industry have been highlighted in studies such as Langkapin, et al. [27] on lotus leaf cutting machines and Langkapin, et al. [28] on lotus seeds sizing machines. These studies aimed to improve efficiency and productivity in specialized processes associated with specific food items.

Studies by Immawan, et al. [29]; Widanarti, et al. [30], and Darma [31] concentrated on optimizing sago processing machinery through the redesign of sago raspers, sieving machines, and extraction equipment, aiming to improve productivity and reduce labor-intensive processes. Furthermore, Punpain [32] introduced a case study on the design of a Konjac Pearl Dropping Machine to address production delays and inconsistencies in Konjac Pearl manufacturing. The machine significantly increased production rates and consistency.

The adoption of microcontroller-controlled machines for specific food production, such as the seafood kanomkrog maker discussed by Supabowornsathian and Swagkla [33], demonstrated the integration of technology to improve production processes.

Furthermore, the integration of smart technologies in machinery performance analysis and the amalgamation of IoT, big data, and AI in agriculture and the food industry have significantly impacted operational efficiency and data-driven decision-making Saetta and Caldarelli [34] and Misra, et al. [35]. Tutul, et al. [36], focusing on the development of a smart food monitoring system utilizing IoT and machine learning, showcased the potential to enhance food quality assessment, reduce waste, and ensure food safety through real-time monitoring and predictive analytics.

The comprehensive literature reviewed above showcases the ongoing evolution of machinery and technology within the food industry. These studies emphasize the importance of designing, developing, and evaluating machines that improve efficiency, reduce manual labor, enhance product quality, and address specific challenges within various food processing sectors.

The proposed study aims to contribute to this body of knowledge by introducing a novel semi-automatic gummy jelly dropping machine, focusing on integrating cutting-edge control mechanisms. Building on previous research on optimizing confectionery production machinery, the evaluation will place a focus on production rates, product uniformity, and adaptability to various operational conditions.

3. Materials and Methods

In the realm of confectionery production, the creation of gummy jelly stands as a meticulous craft, demanding precision and efficiency. Addressing this challenge, our study delves into the intricate process of developing a semi-automatic gummy jelly dropping machine. This innovative machine represents a pivotal stride towards enhancing the manufacturing process of gummy-jelly, promising both efficiency and quality. To methodically navigate this pursuit, our research has been meticulously organized into four distinct steps, each crucial in unraveling the complexities of this technological advancement.

3.1. Step 1: Gummy Jelly Production Process

The first step in crafting gummy jelly involves the meticulous preparation of gel-forming ingredients. This specialized blend, derived from a modified basic formula, comprises 40 grams of 240 Bloom gelatin dissolved in 122 grams of clean water until a clear solution is achieved. Simultaneously, a syrup mixture is created by combining 165 grams of sucrose with 156 grams of glucose syrup and 15 grams of a 50 percent citric acid solution. This concoction is then simmered and heated to precisely 116 degrees Celsius. The resulting gelling mixture is carefully poured into a pot, where it undergoes further boiling and heating until the desired concentration of water-soluble ingredients is attained. Once perfected, the gummy mixture is delicately dropped onto a cornstarch mold and left to cool for a period ranging from 12 to 24 hours. After this setting period, a gentle shake is applied to separate the powder, yielding the final gummy jelly products.

3.2. Step 2: Development of a Semi-Automatic Gummy Jelly Dropping Machine

In this phase, our focus shifted towards the design and fabrication of a semi-automatic gummy jelly dropping machine. Leveraging advanced technology, the machine was meticulously crafted using the Solid Work program. This software allowed us to create a detailed 3D model, ensuring that the dimensions, both in shape and componentry, mirrored the real machine accurately. Such precision was vital to guarantee consistent and error-free fabrication, as well as seamless installation of the machine components [37].

The resulting semi-automatic gummy jelly dropping machine, depicted in Figure 1, is constructed from stainless steel, measuring 36.00 centimeters in width, 56.00 centimeters in height, and 47.00 centimeters in length. Its core functionality relies on a piston mechanism crafted from aluminum, boasting a diameter of 34 millimeters and a length of 142 millimeters, responsible for the precise opening and closing of the jelly drop hole. Ingeniously, a lever on the side of the machine controls a camshaft that, in turn, operates this piston. When the lever is pushed upward, the piston extends outward, opening the gummy drop hole. Conversely, pushing the lever downward causes the piston to retract, sealing the gummy jelly drop hole securely. At the back of the piston lies a reservoir designed to hold the liquid gummy jelly. To maintain the optimum temperature, 80 mm-wide and 400 mm-long heaters with a power rating of 950 watts were strategically placed. This heater ensures consistent warmth for the liquid gummy jelly, enhancing its viscosity and aiding in the dropping process, as illustrated in Figure 2.

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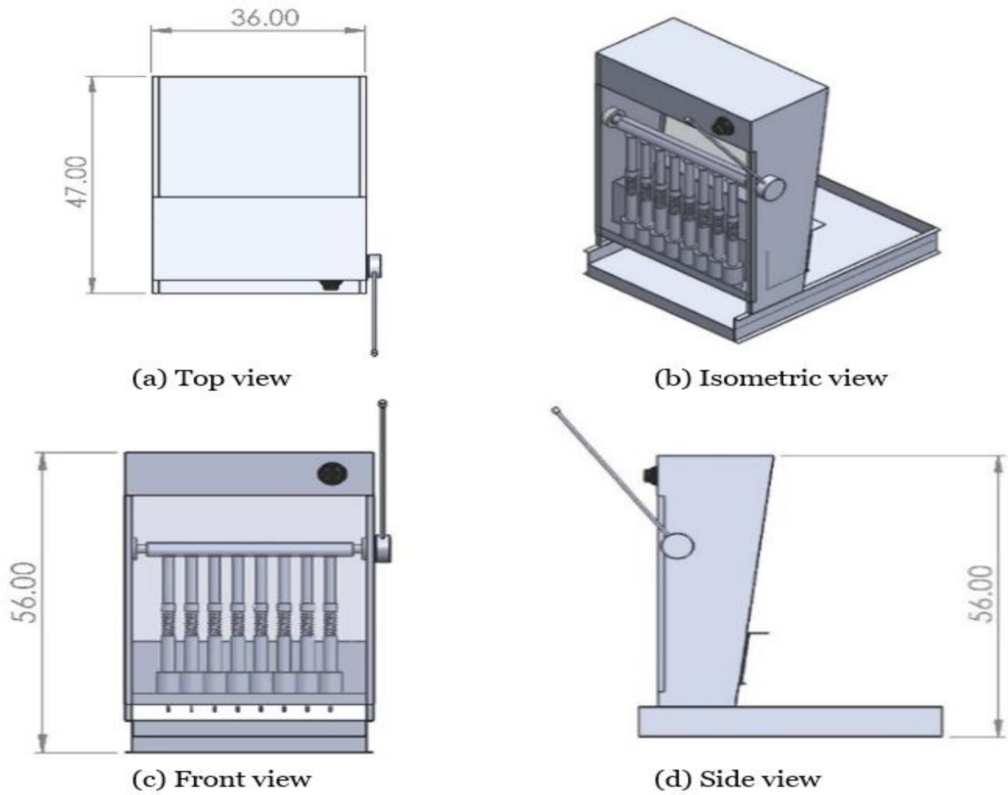

Figure 1.
3D model of the semi-automatic gummy jelly dropping machine.

Figure 2.
Components of the semi-automatic gummy jelly dropping machine.

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3.3. Step 3: Performance Testing and Efficacy Evaluation of the Semi-Automatic Gummy Jelly Dropping Machine

In this phase, rigorous performance testing was conducted on the prototype of the semi-automatic gummy jelly dropping machine. The experiments were meticulously carried out at three distinct temperatures: 80, 100, and 120 degrees Celsius, with 80 gummy jelly samples dispensed per temperature level. Each test was replicated five times to ensure accuracy and reliability in the results.

Data collection focused on three key parameters: 1) working time; 2) the completeness and consistency of the gummy jelly drops; and 3) the extent of loss incurred during the dropping process. This comprehensive dataset was then analyzed to gauge the machine's competence and efficiency. The evaluation process involved utilizing Equation 1, representing the performance of the semi-automatic gummy jelly dropping machine, and Equation 2, illustrating the efficiency of the same machine. These equations furnished vital insights into the performance metrics of the semi-automatic gummy jelly dropping machine.

The calculation of the machine's operating performance is as follows:

$$C = \frac{W}{T} \times 3600 \qquad (1)$$

Where: C represents the performance of the semi-automatic gummy jelly dropping machine, W stands for the weight of materials before entering the semi-automatic gummy jelly dropping machine, and T denotes the time taken for instilling the gummy jelly.

The calculation of the machine's operating efficiency is as follows:

$$N_C = \frac{N_a}{N_T} \times 100 \qquad (2)$$

In the given context, N_C represents the efficiency of the semi-automatic gummy jelly dropping machine, N_a stands for the number of complete and uniformly sized jelly gummies, and N_T denotes the total number of jelly gummies produced.

3.4. Step 4: Evaluation of Gummy Jelly's Physical Properties

This step involves a meticulous assessment of the physical characteristics of the gummy jelly, encompassing several crucial aspects:

1) Size, Shape, and Thickness Testing: The gummy jelly products obtained from the semi-automatic gummy jelly dropping machine, operated at temperatures of 80, 100, and 120 degrees Celsius, were subjected to thorough examination. Thirty random samples from each temperature setting were selected, and each test was replicated three times. The shape and thickness of these gummy jelly samples were precisely measured using a Vernier caliper, ensuring accuracy and consistency.

2) Color Analysis of Gummy Jelly Products: The color properties of the gummy jelly products were meticulously measured using a Konica Minolta spectrophotometer, model CR-400, evaluating the L*, a*, and b* color values. This detailed color analysis provides valuable insights into the visual aspects of the gummy jelly, contributing to its overall appeal.

3) Determination of Water Activity (aw): To assess the amount of water activity present in the gummy jelly, samples were crushed and carefully packed into sample boxes. The evaluation of water activity was conducted using a specialized water activity meter (AQUA LAB Series 3 TE). This measurement is crucial, as it helps characterize the product's moisture content, with typical jellies exhibiting values within the range of 0.7-0.8 [38, 39].

Subsequently, the gathered data underwent statistical analysis using Analysis of Variance (ANOVA) to discern differences in means. Duncan's New Multiple Range Test (DMRT) was employed at a significance level of 0.05 to further explore these variations.

This comprehensive analysis of the gummy jelly's physical properties is vital to ensuring quality, consistency, and consumer satisfaction.

4. Results and Discussion

4.1. An Investigation into the Efficiency and Performance of a Semi-Automatic Gummy Jelly Dropping Machine

The evaluation of the semi-automatic gummy jelly dropping machine prototype was conducted at different temperatures: 80, 100, and 120 degrees Celsius, revealing distinct performance metrics. The instillation times averaged 99.35, 132.31, and 135.09 seconds, respectively (Figure 3). Correspondingly, the machine's productivity was measured at 36.66, 28.95, and 26.77 kilograms per hour in the same order (Figure 4). Figure 5 illustrates efficiency figures of 73.75, 59.25, and 47.50 percent, with the most favorable results observed at a temperature of 120 degrees Celsius across all aspects. At this temperature, the average instillation time for gummy jelly was 99.35 seconds, aligning closely with the research findings of Delgado and Bañón [40] and Sumrit, et al. [16]. The prototype demonstrated an average standard working time of 2.68 minutes for dropping gummy jelly ingredients, resulting in a production rate of 36.66 kilograms per hour and a peak efficiency of 73.75 percent.

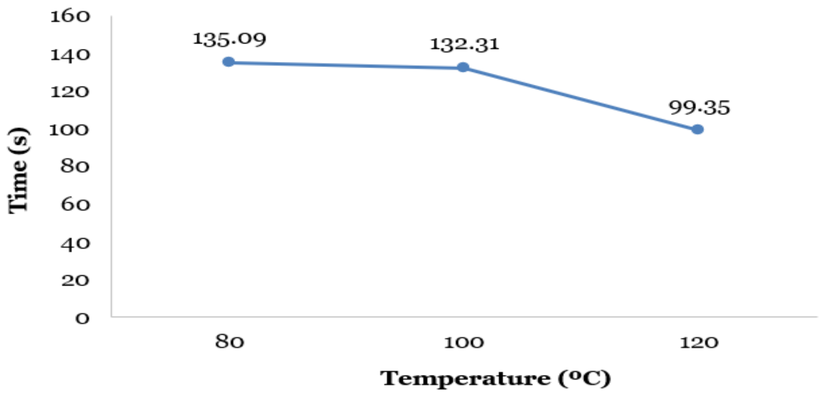

Figure 3.
Average gummy jelly instillation time.

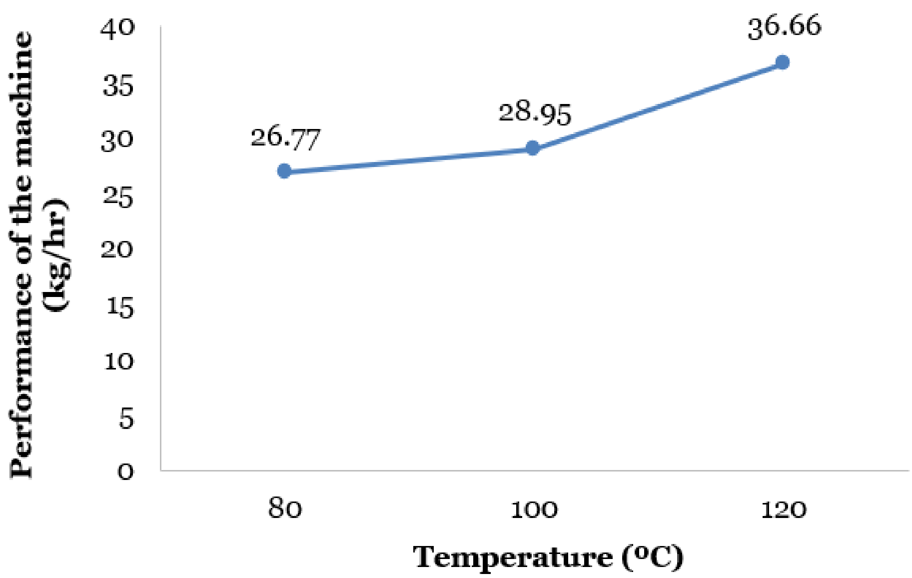

Figure 4.
Average performance of the semi-automatic gummy jelly dropping machine.

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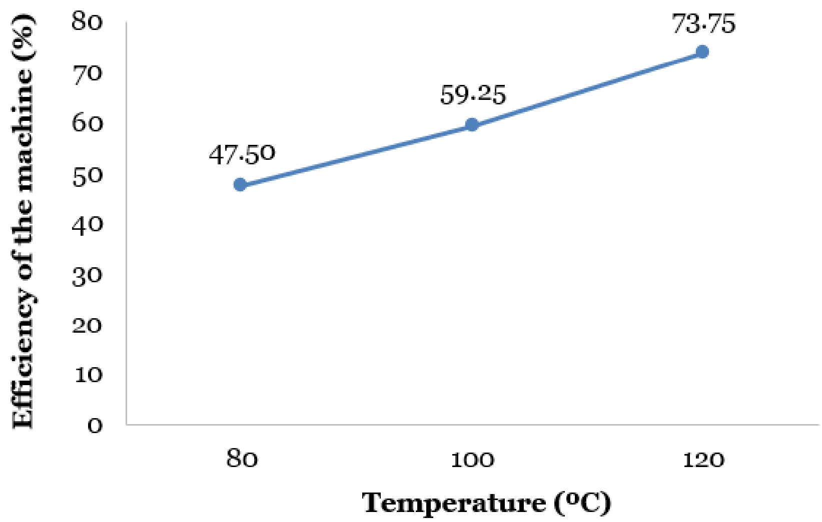

Figure 5.
Average efficiency of the semi-automatic gummy jelly dropping machine.

4.2. Evaluating the Physical Properties of Gummy Jelly

The assessment of gummy jellies' physical attributes at various temperatures revealed significant differences in L, a* color values ($p \leq 0.05$), while b* color values and aw values remained constant. This indicates that different test temperatures induce changes in L* a* color values, as illustrated in Table 1. Moreover, there were statistically significant variations ($p \leq 0.05$) in Hardness, Gumminess, and Chewiness. Conversely, Cohesiveness and Springiness values exhibited no significant differences among the gummy jelly samples, as detailed in Table 2.

Gummy jelly produced using the semi-automatic dropping machine at a temperature of 120 degrees Celsius exhibited a moisture content of 12.07 percent. Its lightness value measured 52.63±4.67, the red/green value stood at 0.27±0.11, and the yellow/blue value was recorded as 4.08±3.13. Additionally, the product displayed a hardness value of 1027.75 grams, Gumminess at 916.25 grams, and a water activity of 0.80.

These findings align with previous research by Jiamjariyatam [15] and Periche, et al. [39], highlighting the critical role of water activity (aw) in microbial growth and chemical reactions within the product, potentially affecting its stability. Generally, gummy jellies with a moisture content below 20 percent typically exhibit an aw value within the 0.7-0.8 range.

Table 1.
Color (L, a*, b*) and water activity (aw) of gummy jelly at different temperatures.

Temperature (°C)	L*	a*	b* ^{ns}	a_w^{ns}
80	39.47±1.25^{b}	1.12±0.03^{a}	6.31±0.42	0.81±0.01
100	38.65±1.82^{b}	0.50±0.41^{ab}	5.57±0.54	0.78±0.01
120	52.63±4.67^{a}	-0.27±0.11^{b}	4.08±3.13	0.80±0.00

Note: Means ± S. D. with different superscript letters in the same column (a-b) indicate significant differences ($p < 0.05$); the superscript "ns" indicates no significant differences among the means in the same column; the letters L*, a*, and b* represent each of the three values the CIELAB color space uses to measure objective color and calculate color differences.

Table 2.
Textural characteristics of gummy jelly at different temperatures.

Temperature (°C)	Hardness (g)	Cohesiveness^{ns}	Springiness^{ns}	Gumminess (g)	Chewiness (g)
80	845.00±32.98^{c}	0.91±0.02	0.93±0.02	780.00±25.86^{c}	721.75±32.82^{b}
100	1225.25±92.80^{a}	0.91±0.00	0.94±0.02	1145.25±85.60^{a}	1071.50±100.69^{a}
120	1027.75±79.83^{b}	0.88±0.02	0.91±0.02	916.25±56.63^{b}	834.00±52.96^{b}

Note: Means ± S. D. with different superscript letters in the same column (a-c) indicate significant differences ($p < 0.05$); the superscript "ns" indicates no significant differences among the means in the same column.

5. Conclusion

The semi-automatic gummy jelly dropping machine is constructed from stainless steel, with dimensions of 36.00 centimeters in width, 56.00 centimeters in height, and 47.00 centimeters in length. It employs a piston mechanism made of aluminum, featuring a 34-millimeter diameter and a length of 142 millimeters, used for opening and closing the jelly dropping hole. The piston incorporates a back reservoir designed for liquid gummy jelly, which is heated by an 80-millimeter wide and 400-millimeter-long heater powered by 220 volts of alternating current at 950 watts. Extensive testing was conducted at three temperature levels: 80, 100, and 120 degrees Celsius. Results indicate that the optimal temperature for the semi-automatic gummy jelly dropping machine is 120 degrees Celsius, achieving an average dispensing time of 99.35 seconds. The machine's production capacity is 36.66 kilograms per hour, with a maximum efficacy of 73.75 percent, resulting in a gummy jelly product with a moisture content of 12.07 percent, a lightness (L) of 52.63±4.67.63, a red/green (a*) of 0.27±0.11, and a yellow/blue (b*) of 4.08±3.13. Furthermore, the hardness measured 1027.75 grams, the gumminess was 916.25 grams, and the water activity (aw) was 0.80. Remarkably, no microbial growth was detected in the final product.

6. Recommendation

6.1. Further Investigation on Temperature Control Mechanisms

Further study should focus on enhancing temperature regulation mechanisms in the semi-automatic gummy jelly dropping machine. To address the problem of liquid gummy jelly cooling too quickly during dispensing, it would be beneficial to investigate advanced heating solutions, such as precision-controlled heating elements or adaptive temperature sensors.

6.2. Optimization of the Dispensing Mechanism

Optimizing the dispensing mechanism for different gummy jelly formulations and viscosity levels warrants attention. Exploring adjustable piston mechanisms or nozzle designs adaptable to various gummy jelly consistencies might enhance the machine's versatility and efficiency.

6.3. Long-Term Stability and Maintenance

Assessment of the semi-automatic gummy jelly dropping machine's long-term stability and maintenance requirements is crucial. Conducting extended operational tests and durability studies can provide insights into its reliability over extended use, while implementing user-friendly maintenance protocols can ensure sustained performance.

6.4. Integration of Smart Monitoring Systems

Considering the integration of smart monitoring systems or sensors to oversee gummy jelly viscosity, temperature, and dispensing consistency in real-time could be beneficial. This proactive approach could enable automatic adjustments within the machine, ensuring continuous, uninterrupted dispensing.

6.5. Collaboration for Industrial Implementation

Collaboration with confectionery manufacturers or food production industries would be advantageous for real-world validation and industrial-scale implementation. Engaging stakeholders in the field can facilitate feedback, allowing for practical adjustments tailored to industrial requirements.

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Transparency:

The authors confirm that the manuscript is an honest, accurate, and transparent account of the study; that no vital features of the study have been omitted; and that any discrepancies from the study as planned have been explained. This study followed all ethical practices during writing.

Competing Interests:

The authors declare that they have no competing interests.

Authors' Contributions:

All authors contributed equally to the conception and design of the study. All authors have read and agreed to the published version of the manuscript.

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