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Development of Gummy Candy with Date Paste and Natural Preservatives: Rheological and Physical Properties

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ABSTRACT

This study aimed to enhance gummy candy by incorporating date paste and varying ratios of gelling agents—gelatin (12%, 15%, and 17%) and starch (2%, 4%, and 6%) to evaluate their effects on rheological and physicochemical properties. Additionally, the antimicrobial activity of cinnamon extract and citric acid solution was investigated as natural preservatives against *Escherichia coli* O:157 (wild-type strain 93111), *Staphylococcus aureus subsp. aureus* (ATCC 25923), and *Candida albicans*. The minimum inhibitory concentration (MIC) for citric acid solution against *Escherichia coli*, *Staphylococcus aureus* and *Candida albicans* were recognized at the concentrations 2%, 1% and 0.5% respectively; while it was 4%, 0.03% and 4% respectively for the cinnamon extract. The minimum bactericidal concentration (MBC) of citric acid solution was recorded only at 0.5% for both *E. coli* and *S. aureus*, while for cinnamon extract, it was recorded at 4% for *C. albicans*. The final concentrations incorporated into the gummy candy formulations were 2% citric acid solution and 4% cinnamon extract. The gummy candy treatments displayed pseudoplastic behavior. Gel strength values ranged from 9.20 to 24.68 N, moisture content from 19.34% to 23.27%, and water activity from 0.68 to 0.74. The DPPH free radical scavenging activity ranged between 72.58% and 83.9%. Total soluble solids (TSS) ranged from 61.3 to 75.4°Brix, while total sugars and reducing sugars were between 50.15%–63.4% and 42.35%–53.77%, respectively.

1. Introduction

Confectionery products, particularly gummies and jellies, are widely popular among both children and adults, especially those under 17 years of age (Teixeira-Lemos et al., 2021). However, increasing concerns regarding synthetic additives have driven interest in natural, fruit-based ingredients that enhance nutritional value and provide bioactive compounds, such as antioxidants (Schweiggert, 2018; Archaina et al., 2019; Vergara et al., 2020). Date fruits, a staple crop in the Middle East and Africa, are rich in carbohydrates, dietary fibers, phenolic antioxidants, and essential vitamins, making them a promising ingredient for functional food products (Anthony et al., 2020 and Khalid et al., 2017). Incorporating date fruits into gummy formulations can enhance nutritional profiles and introduce bioactive properties (Maqsood et al., 2020). A critical challenge in confectionery production lies in ensuring microbial safety while reducing reliance on synthetic preservatives, which are associated with adverse health effects and microbial resistance (Pisoschi et al., 2018; Gyawali and Ibrahim, 2014). Natural antimicrobials derived from plants, bacteria, and other sources are increasingly preferred due to their ability to inhibit microbial growth without harmful side effects (Quinto et al., 2019). Traditional gummy production involves blending fruit or herb juices with sweeteners and gelling agents to achieve a dry-sticky texture and firm chewability (Jiamjariyatam, 2018). The process typically includes boiling gel components and sugars at high temperatures, followed by mixing with acids, flavors, and colorants, and then shaping and cooling (Hay, 2016).

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Gelatin, derived from animal collagen, is a key gelling agent that imparts the characteristic rubbery texture of gummies (Tau and Gunasekaran 2016). Its functional properties are influenced by factors such as collagen origin, ionic conditions, concentration, and thermal history (Wang and Hertal 2022). Additionally, starch, a biodegradable polysaccharide, plays a crucial role in thickening, stabilizing, and enhancing the textural properties of gummies (Liu and Xu, 2019; Kumar et al., 2020 and Dereje, 2021). Achieving optimal gummy texture requires balancing amylose retrogradation and amylopectin stability (Wolde et al., 2023).

Rheology, the study of the deformation and flow of materials, is fundamental to understanding and improving food texture and structure. This interdisciplinary field bridges physics, material science, and food engineering, providing critical insights into the mechanical properties that influence food processing and consumer perception (Dipak, 2017; Sanaa et al., 2021).

Confectionery gels, such as gummies, jellies, and marshmallows, represent complex hydrocolloid matrices where ingredients like starch, gelatin, and sugars interact to create distinctive textures (Wang and Hertal, 2022; Takeungwongtrakul, 2020).

This study aims to investigate the physical and rheological properties of date-based gummy candies. Specifically, it seeks to optimize gelatin and starch concentrations and evaluate their effects on the physicochemical, textural, and sensory characteristics of the candies.

2. Materials and Methods

Materials

The study utilized Siwi variety date fruits, a widely cultivated and economically significant crop in El Badrashin, Egypt. These dates were chosen for their high carbohydrate content, dietary fibers, and phenolic antioxidants. Additional ingredients included locally sourced sucrose and cinnamon powder from the Egyptian market. Gelatin, citric acid, and corn starch were procured from PIOCHEM, Egypt, while glucose syrup was supplied by the National Company for Maize Products, Egypt.

Preparation of Date Paste (DP)

The Siwi date fruits were thoroughly washed under running water to remove dust and microscopic contaminants. Seeds were manually removed, and the pulp was blended into a smooth paste using an electric blender. The prepared DP was stored in airtight containers and kept in a deep freezer at −18°C until further use, following the method described by Meranda et al. (2021).

Microbial Strains and Culture Media

The study employed microbial strains, including Escherichia coli O:157 (wild-type strain 93111), Staphylococcus aureus subsp. aureus (ATCC 25923), and Candida albicans. These strains were chosen for their relevance to food safety and spoilage. They were provided by the Unit of Microbiology at Cairo University Research Park, Faculty of Agriculture, Cairo University. Bacterial strains were grown on nutrient agar at 37°C for 24 hours, while the yeast strain was cultured on potato dextrose agar at 28°C for 24 hours. Nutrient broth (NB) and potato dextrose broth (PDB) were prepared according to Atlas (2010). Microbial suspensions were standardized to 1.5×10^8 CFU/mL using a 0.5 McFarland standard and then diluted to 1:1 by sterile distilled water (SDW).

Substances

A 4% cinnamon extract was prepared by dissolving 4 g of cinnamon powder in 100 mL of sterile deionized water (SDIW). The mixture was shaken at 200 rpm for 2 hours at room temperature, refrigerated overnight at 4°C, and centrifuged at 8000 rpm for 10 minutes at 4°C. A 2% citric acid solution and a 0.2 mg/mL microbial growth indicator (2,3,5-triphenyl tetrazolium chloride, TTC) were also prepared in SDIW. All solutions were sterilized using a 0.22 µm syringe filter (MCE).

Broth Microdilution Assay Method

The antimicrobial effectiveness of the citric acid solution and cinnamon extract were assayed by using the common broth micro-dilution method (Balouiri et al., 2016). In sterile flat bottom 96- well microplat with led, each well consisted of a total volume of 120µl; while each microbial strain was tested in a separate plate. The plate layout was designed as follow: A1 and B1 containing 120µl SDIW as blank sample. The wells from A2 to H2 contained (100µl broth medium, 10µl microbial suspension and 10µl TTC) as the positive control. The wells from A4 to H4 were for the negative control for citric acid solution, A4 well filled with100 µl broth medium and 100 µl of 2% citric acid solution. Serial twofold dilutions ranged from 2g/100ml (A4) to 0.01g/100ml (H4) was performed, then 10µl SDIW and 10µl TTC were added. The same steps were performed for the wells from A9 to H9 for the 4% cinnamon extract, serial twofold dilutions ranged from 4g/100ml (A9) to 0.03g/100ml (H9) was performed. The wells from $A_{5,6,7}$ to $H_{5,6,7}$ were allocated for testing the citric acid; it was performed in triplicates. For the first three wells each well filled with 100µl of broth medium and 100µl of 2% citric acid solution, serial of twofold dilutions was performed then 10µl of TTS and 10µl of microbial suspension were added. The same steps were performed for the wells $A_{10,11,12}$ to $H_{10,11,12}$ for the 4% cinnamon extract. Finally, all the plates sealed with stretch film and incubated at 37ºC and 28ºC for bacteria and yeast strains respectively for 24h. The minimum inhibitory concentrations (MIC) for each test was assessed visually by determining the wells of test samples that has change of TTC color from colorless (oxidized form) to red (when reduced by the biologically active microbial cell). The wells that remained clear, the minimum bactericidal concentration (MBC) and minimum fungicidal concentration (MFC) were determined by inoculating the corresponding agar medium with 50µL from the selected wells, incubated for 24h at the suitable growth temperature, then the number of appeared colonies was counted.

Preparation of Date Gummy Candy

Date gummy candy was prepared using a modified method based on Rivero et al. (2021). The process involved dissolving sugar and glucose in cinnamon extract, followed by the addition of date paste, which was homogenized. Starch was incorporated at 26°C for 3 minutes, and gelatin was mixed at 25°C for 10 minutes for swelling. The mixture was heated to 85°C for 10 minutes to facilitate gelatin gelation and starch gelatinization. Citric acid (1.5%) was added and blended for 10 minutes at room temperature (30°C), then reheated to 85°C to form a liquid gummy mixture. The mixture was poured into molds and dried in a laboratory oven at 21°C and 35% relative humidity for 24hs. The final gummy candies, weighing approximately 5grams each, were released from the molds after cooling.

Table 1. Date gummy candy composition consisting of different concentrations of gelatin and starch

treatments	Gelatin %	Starch %	Cinnamon extract %	Date paste %	Sugar %	Glucose %
A	13	-----	32	30	20	5
B	15	-----	30	30	20	5
C	17	-----	28	30	20	5
D	13	2	30	30	20	5
E	13	4	28	30	20	5
F	13	6	26	30	20	5
G	15	2	28	30	20	5
H	15	4	26	30	20	5
I	15	6	24	30	20	5
J	17	2	26	30	20	5
K	17	4	24	30	20	5
L	17	6	22	30	20	5

- 1.5 % citric acid was added for all ingredients/100g mixture

Rheological Properties of Date Gummy Candy Paste

The rheological properties of the prepared date gummy candy pastes were analyzed to evaluate their flow behavior, a critical factor in food processing and formulation. Parameters such as viscosity, shear rate, and shear stress were measured using a Brookfield AMETEK Rheocalc T 2.1.52 (USA). The RV7 spindle was utilized for these measurements, adhering to the procedures outlined in the

Brookfield Manual (2020).

Texture Profile Analysis (TPA) and Gel Strength of Date Gummy Candy

The texture profile analysis (TPA) of the date gummy candy samples was conducted at room temperature using a Brookfield texture analyzer (Texture Pro CT V1.8 Build 31) fitted with a 50 mm diameter acrylic cylindrical probe (TA25/1000). The gummy candy samples were prepared according to the standard protocol described earlier. A two-cycle compression test was performed following the method detailed by Supavititpatana et al. (2008), allowing for the assessment of textural attributes such as hardness, cohesiveness, gumminess, and chewiness.

Detailed TPA Test Settings

Target Mode: Distance, Compression Distance: 3mm (30% of the original gel height), Time: 10.0 seconds, Trigger Type: Auto (force),

Trigger Force: 5.0N,Speeds: Pre-test, test, and post -test speeds set to 1.0mm/s,

Load Cell: 5kg, calibrated with a 5kg weight.

Gel strength was evaluated using a texture analyzer (Brookfield Engineering Labs, Texture Pro CT V1.8 Build 31). Before conducting the assessment, the candies samples were permitted to stabilize at room temperature for 30min. The measurement parameters encompassed a 12.5 mm flat bottomed aluminum cylindrical probe TA10 probe, a test speed of 1.0mm/s, a return speed of 1.0mm/s, and a target depth of 10mm. Gel strength denotes the maximum force was determined when the probe penetrated 4mm into the sample. Readings are the average of three determinations (Ren et al., 2024).

Physicochemical Analysis

pH Measurement

The pH of the samples was measured using a pH meter (EZODO pH 5011). For analysis, 2g of each sample was homogenized with 6mL of distilled water until fully dissolved. All measurements were performed in triplicate (Kia et al., 2020).

Total Soluble Solids (TSS)

The total soluble solids (°Brix) were determined using a hand refractometer (PAL-1, Atago). To prepare the samples, 5g of the gummy candy was homogenized with 20mL of distilled water until complete dissolution. The analyses were conducted in triplicate (Kia et al., 2020).

Moisture Content

Moisture content was assessed using an oven set at 105°C. The percentage of moisture content was calculated using the following equation, as per AOAC (2005):

$$moisture\ content\ \% = \frac{w1 - w2}{w1} \times 100$$

Where W1 is the weight of the sample before treatment (g), W2 is the weight of the sample after treatment (g). The analyses were carried out in triplicate.

Antioxidant Activities (DPPH Assay)

The antioxidant activity of the date gummy candy was assessed using the DPPH radical-scavenging assay. For each sample, 5g was mixed with 20mL of 50% ethanol and homogenized at 1000 rpm for 3 minutes using a magnetic stirrer. The homogenate was heated at 40°C for 20 minutes with continuous magnetic stirring to enhance solubilization and then centrifuged at 10,000 × g for 20 minutes. The supernatant was collected and used for the DPPH assay, following the method described by Hani et al. (2015), with slight modifications. To perform the assay, 1mL of the sample extract was mixed with 3mL of 100µM 2,2-diphenyl-1-picryl hydrazyl (DPPH) solution prepared in 80% ethanol. The mixture was incubated in the dark for 30 minutes to prevent light-induced degradation. Absorbance was then measured at 517nm using a spectrophotometer. The percentage of DPPH radical-scavenging activity was calculated using the following equation:

$$\text{DPPH scavenging activity} = \frac{A_{517}^{control} - A_{517}^{sample}}{A_{517}^{control}} \times 100$$

Where A sample represents the absorbance of the date gummy candy solution and A control represents the absorbance of the blank solution (Hani et al., 2015).

Water Activity

The water activity of date gummy candy was measured using a Lab Start-a_w device (Novasina). Analyses were conducted in triplicate.

Color Attributes

The color properties of date gummy candy were assessed using a Chroma Meter (Jnway 6715vv/ vis, USA), with measurements of the following parameters: L*: Degree of lightness, a*: Degree of greenness (negative values) to redness (positive values), b*: Degree of blueness (negative values) to yellowness (positive values). Measurements were performed in triplicate.

Total and Reducing Sugars

Total and reducing sugars were determined using the AOAC (2023) method, which involves grinding and mixing the sample for uniformity, transferring 2mL of the sample solution to a Folin–Wu tube, adding 2mL of alkaline copper solution, heating the mixture in a boiling water bath, cooling, adding phosphomolybdic acid solution, diluting to 25mL with a 1:4 phosphomolybdic acid solution, allowing it to stand for 10-15 minutes, and finally measuring absorbance at 420nm using a photoelectric colorimeter with water as a blank and a standard solution for calibration. To measure total sugars, 50mL of the extracted sugar solution was transferred to a 100 mL volumetric flask. The solution was treated with 10mL of HCl (1:1) and left to stand at room temperature (≥ 20°C) for 24 hours. Neutralization was achieved using concentrated NaOH with phenolphthalein as an indicator, and the solution was diluted to 100 mL. The total sugar content was determined from this solution.

Sensory Evaluation

The sensory properties of date gummy candy were evaluated by a panel for the following attributes: Color, Texture, Taste, Odor, Chewiness, Overall Palatability (Jiamjariyatam 2018)

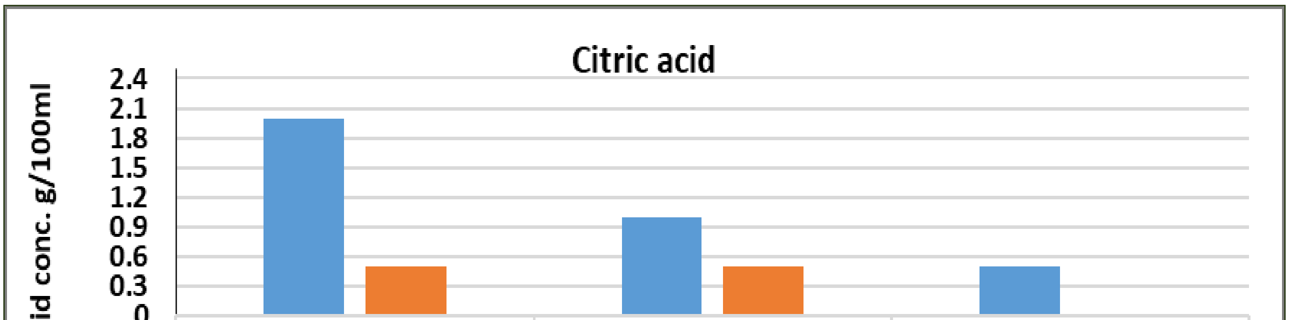
Statistical Analysis

All measurements were conducted in triplicate unless otherwise specified. Data are presented as the mean ± standard deviation (SD). One-way analysis of variance (ANOVA) and Tukey's test were performed for multiple comparisons using SPSS Statistics 22 software (SPSS, USA). Statistical significance was set at $p < 0.05$.

3. Results and Discussion

Determination of MIC and MBC for antimicrobials

Citric acid solution and cinnamon extract were selected for this study as natural antimicrobial agents due to their documented antimicrobial properties in previous studies (Nabavi et al., 2015; Eliuz, 2020; Patel et al., 2022; Li et al., 2023; Al-Garadi et al., 2023 and Lee et al., 2023), as well as their recognition as Generally Recognized as Safe (GRAS) substances (Muhammad and Dewettinck, 2017 and EPA, 1992). The minimum inhibitory concentration (MIC) and minimum bactericidal concentration (MBC) of these antimicrobials were evaluated, as shown in Figures 1 and 2.



	E. coli	Staph.	Candida
MIC	2	1	0.5
MBC	0.5	0.5	0

Figure 1. MIC and MBC of citric acid against *Escherichia coli* O:157, *Staphylococcus aureus* sub sp. aureus and *Candida Albicans*

It was more accurate to proceed the MBC, specially with cinnamon extract, because sometimes the color of the antimicrobial solutions may shads the resulted color of TTC . The final chosen concentration that were added for citric acid solution is greater than the MIC (2%), while for the cinnamon extract was that inhibited 100% of C. albicans (4%). Both antimicrobials affect positively on the flavor of the product.

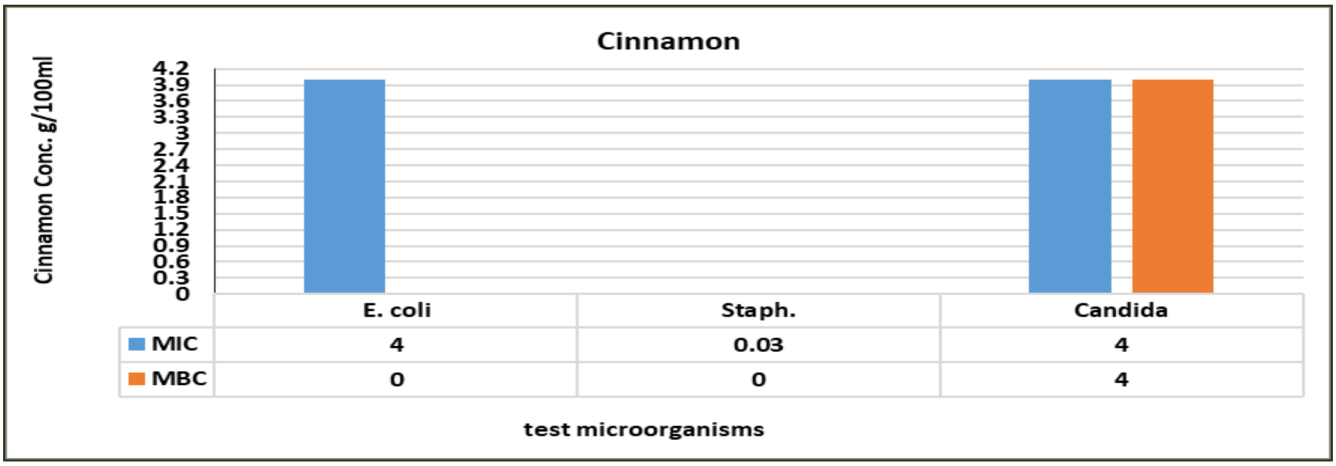


Figure 2. MIC and MBC of cinnamon extract against *Escherichia coli* O:157, *Staphylococcus aureus* sub sp. aureus and *Candida Albicans*

Rheological Properties of Date Gummy Candy Paste

The apparent viscosity of date gummy candy pastes was investigated at two temperatures, 30°C and 85°C, across shear rates ranging from 1.05 to 6.29 s^{-1}. Figures 3 and 4 illustrate the effects of temperature, shear rate, and shear stress on the rheological properties of the paste.

Effect of Temperature on Shear Thinning Behavior

Figure 3 highlights the temperature-dependent shear-thinning behavior of date gummy candy pastes. At 30°C, the paste exhibited higher viscosity compared to 85°C, indicating stronger intermolecular interactions at lower temperatures. The reduction in viscosity at 85°C can be attributed to the increase in thermal energy, which disrupts molecular interactions, resulting in greater intermolecular distances and reduced chain overlap and entanglement. This trend aligns with findings reported for other gelling agents, such as pectin, where increasing temperature led to similar decreases in viscosity (Kar and Arslan, 1999 and Hosseini et al., 2010).

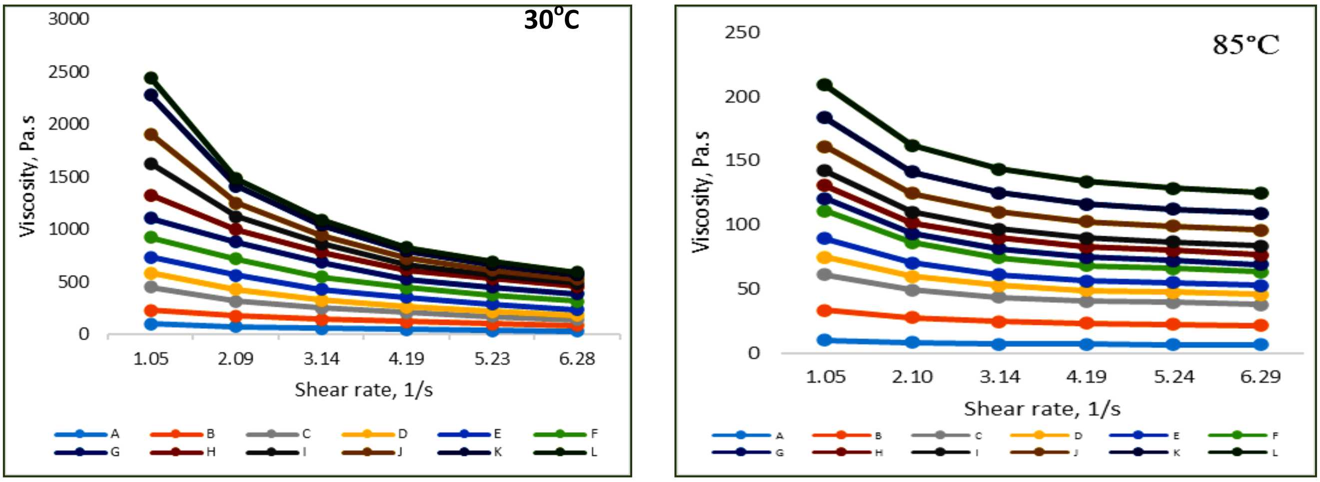


Figure 3. Effect of temperature on shear thinning behavior of date gummy candy pastes

Effect of Shear Rate and Shear Stress

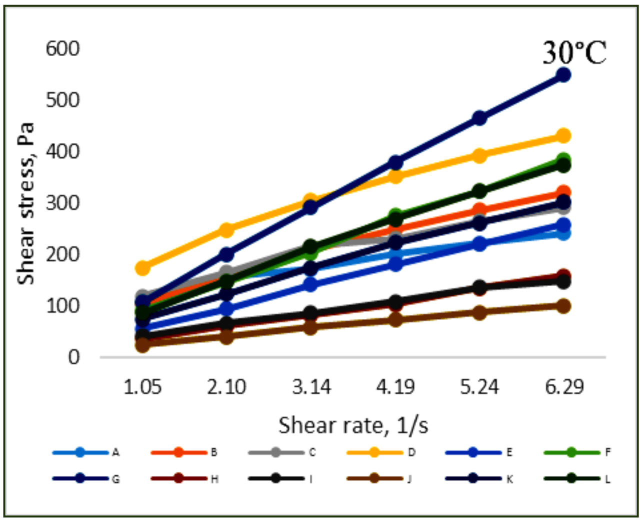
Figure 4 shows the relationship between shear rate and shear stress at 30°C and 85°C. At both temperatures, the shear stress increased with shear rate, confirming the non-Newtonian, shear-thinning (pseudoplastic) behavior of the paste and fitted well to power law equation:

$$\tau = K\,\gamma^{n}$$

Where, τ is shear stress (Pa), *K* is consistency index (Pa.s), γ is shear rate (s^{-1}), n is the dimensionless flow behavior index.

Shear thinning occurs when the rate of molecular disentanglement caused by shear forces exceeds the rate of network formation. As the molecules align in the direction of flow, they offer less resistance, leading to a reduction in viscosity. This behavior facilitates industrial processes such as pouring, extrusion, and shaping (Rafe and Masood, 2014).

The degree of pseudoplasticity observed in the pastes is influenced by the type and concentration of the gelling agent used. The interaction between these agents and the date matrix modulates the paste's flow properties under various processing conditions. Such properties are advantageous in food manufacturing, as they ensure ease of processing under shear conditions while maintaining structural stability at rest.



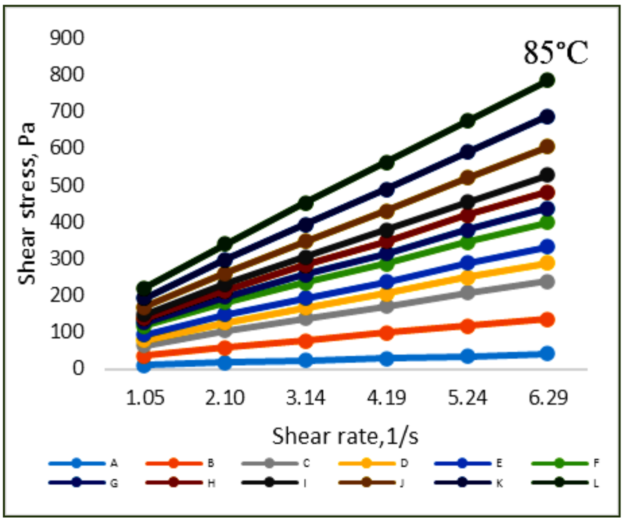


Figure 4. Effect of Shear Rate on Shear Stress of date gummy pastes at different temperatures

The rheological parameters of date gummy candy pastes at 30 and 85°C were determined based on both ascending (upward) and descending (downward) shear curves. The results are presented in Tables (2) and (3), which includes consistency coefficient (K), flow behavior index (n), and coefficient of determination (R^2). These parameters describe the flow behavior and structural stability of the pastes.

Thixotropic effect of date gummy candy paste

The rheological analysis of date gummy candy pastes revealed temperature-dependent behavior. At 30°C, the pastes exhibited weak thixotropic properties, with flow behavior index (n) values ranging from 0.484 to 1.48 (upward curves) and 0.322 to 0.805 (downward curves). The consistency coefficient (K) varied between 115.11 and 391.81 Pa.s for upward curves and 59.594 to 205.84 Pa.s for downward curves. At 85°C, stronger thixotropic behavior was observed, with reduced n values (0.183–0.436 for upward curves and 0.311–0.43 for downward curves) and significantly lower k values (9.363–25.652 Pa.s for upward curves and 11.913–33.368 Pa.s for downward curves). These changes highlight reduced viscosity and enhanced shear-thinning behavior at higher temperatures.

Table 2. The rheological parameters of date gummy candy pastes at 30°C

Treatments	Ascending curve (upwards)			Descending curve (downwards)		
	K	n(-)	R^2	K	n(-)	R^2
A	115.11	0.638	0.9681	59.594	0.532	0.9992
B	138.24	0.484	0.9744	151.9	0.627	0.9839
C	235.62	0.734	0.9874	205.84	0.71	0.9991
D	158.89	0.696	0.9471	96.662	0.705	0.9994
E	253.51	0.785	0.9849	183.35	0.756	0.9936
F	241.2	0.625	0.9934	146.44	0.747	0.9977
G	187.87	0.552	0.9968	94.298	0.332	0.9374
H	208.71	0.633	0.9641	103.3	0.572	0.9539
I	317.24	1.231	0.9968	151.79	0.57	0.9798
J	296.15	1.139	0.9995	137.77	0.771	0.9931
K	391.81	1.205	0.9996	190.74	0.805	0.998
L	172.31	1.148	0.9983	82.14	0.74	0.9972

Table 3. The rheological parameters of date gummy candy pastes at 85°C

Treatments	Ascending curve (upwards)			Descending curve (downwards)		
	K	n(-)	R^2	K	n(-)	R^2
A	10.291	0.268	0.9718	14.871	0.437	0.9977
B	23.143	0.237	0.9929	31.578	0.383	0.9911
C	27.411	0.297	0.9777	36.38	0.41	0.9872
D	13.471	0.31	0.983	15.395	0.368	0.9994
E	14.659	0.436	0.9808	13.995	0.368	0.9953
F	21.485	0.408	0.9912	21.243	0.389	0.9977
G	9.3635	0.239	0.961	11.913	0.359	0.9977
H	10.26	0.183	0.9878	13.498	0.311	0.9815
I	11.067	0.304	0.9757	13.769	0.346	0.9975
J	18.179	0.241	0.934	24.577	0.368	0.998
K	22.029	0.307	0.9533	26.234	0.348	0.9867
L	25.652	0.274	0.9953	33.368	0.403	0.9965

Texture Profile Analysis (TPA) of Date Gummy Candy

The texture analysis of date gummy candies demonstrates considerable variation in their physical properties based on formulation and processing conditions. Key observations are outlined below:

Gel Strength

Gel strength ranged from 9.20N (Sample A) to 24.67N (Sample I). Sample I exhibited the highest gel strength, indicating a more robust gel network structure, likely due to higher binding capacity or optimized formulation. Conversely, Sample A had the weakest gel strength, suggesting a less cohesive structure. The differences highlight the role of formulation components in determining the firmness and overall gel integrity (Cai et al., 2017) and (Renaldi et al., 2022).

Hardness

Hardness values varied significantly, ranging from 2.989N (Sample D) to 16.04N (Sample L). Sample L exhibited the highest hardness, which correlates with its dense structure and strong intermolecular forces. In contrast, Sample D demonstrated the lowest hardness, suggesting a softer, less rigid texture. This variability reflects the balance between ingredient composition, particularly hydrocolloid concentrations and sugar levels (Zhao et al., 2022 and Altan Kamer et al., 2019)

Cohesiveness

Cohesiveness values ranged from 0.63 (Sample H) to 1.12 (Sample L). Sample L showed the highest cohesiveness, indicating superior internal bonding and resistance to deformation, while Sample H had the lowest cohesiveness, reflecting weaker structural integration. According to (Ge et al., 2021) cohesiveness is influenced by the interaction of gelatin and amylose in starch-gelatin systems.

Springiness

Springiness values ranged from 1.01 mm (Sample D) to 1.97mm (Sample A). Sample A, with the highest springiness, exhibited excellent elasticity, which contributes to a bouncy and resilient texture. Sample D, with the lowest springiness, suggests a more brittle structure with limited recovery after deformation. This property directly influences the consumer experience of chewiness (Marfil et al. 2012).

Gumminess

Gumminess values ranged from 2.98N (Sample D) to 15.54N (Sample L). Sample L had the highest gumminess, reflecting its combination of high hardness and cohesiveness, which contributed to a dense, sticky texture. Sample D, with the lowest gumminess, likely has a softer and less cohesive structure, making it easier to chew. These results align with Wang and Hartel (2022), who served that higher gelling agent concentrations increase gumminess.

Table 4. Texture properties of date gummy candies

Sample	Gel strength, N	Hardness ,N	Cohesiveness	Springiness, mm	Gumminess, N
A	9.2000^{a}	4.66^{b}	0.84b^{c}	1.97^{d}	3.92^{b}
B	12.35^{e}	9.63^{f}	0.93^{cd}	1.6^{b}	9.01^{f}
C	11.64^{d}	11.42^{h}	0.95^{cd}	1.94^{d}	10.58^{h}
D	10.62^{c}	2.989^{a}	0.8^{b}	1.01^{a}	2.98^{a}
E	15.14^{h}	6.61^{d}	0.95^{cd}	1.76^{cd}	6.24^{d}
F	12.14^{e}	8.72^{e}	0.9^{bcd}	1.66^{bc}	7.81^{e}
G	9.62^{b}	10.97^{g}	0.9^{bcd}	1.9^{ed}	8.74^{f}
H	14.53^{g}	5.73^{c}	0.63^{a}	1.53^{b}	5.44^{c}
I	24.67^{j}	14.78^{j}	0.95^{cd}	1.58^{b}	12.21^{i}
J	14.53^{g}	11.17^{gh}	0.95^{cd}	1.79^{cd}	9.75^{g}
K	13.53^{f}	13.83^{i}	0.99^{d}	1.9^{ed}	10.36^{h}
L	22.29^{i}	16.04^{k}	1.12^{e}	1.84^{de}	15.54^{j}

Different letters in the same column indicate a significant difference ($P < 0.05$).

The physiochemical properties of date gummy candies

The physiochemical properties of date gummy candies were analyzed, revealing significant differences across treatments (Table 5). These variations reflect the impact of formulation and ingredient composition on the quality attributes of the candies. Key observations are discussed below:

pH measurements

In the production of gelatinous desserts, citric acid serves as a flavoring agent and enhances the structural integrity of the starch-gelatin matrix (Punia, 2020). Additionally, it facilitates pH adjustment to an optimal range of 3.0 to 3.5 (Roukas & Kotzekidou, 1987). This aligns with our findings, where the pH values of all samples fell between 3.2 and 3.7. Such low pH levels effectively inhibit the growth of most microbial pathogens, except acidophilic ones. Furthermore, Nikawa et al. (2008) demonstrated that consuming citric acid in chewing gum significantly reduced periodontal pathogens in saliva.

Moisture Content

The moisture content of date gummy candies ranged from 19.34% (Sample G) to 23.28% (Sample C), falling within the recommended values for gummy products, ensuring good preservation. These levels are consistent with previous studies reporting a moisture content of 18–24% in gummy candies (Periche et al., 2016 and Mutlu et al., 2018). Moisture acts as a plasticizer, aiding in gel formation, with gelatin demonstrating high water affinity, particularly in the presence of sucrose and starch (Efe and Dawson, 2022). Although the moisture levels are low, microbial stability may depend on controlling localized moisture accumulation.

Water Activity (aw)

Water activity (aw) values ranged from 0.68 (Samples E and H) to 0.74 (Sample J). These values fall within the range for intermediate-moisture foods, providing stability against bacterial growth while remaining susceptible to osmophilic yeasts and molds (Tapia et al., 2020). The high sugar content in gummy candies binds free water, reducing (aw) and inhibiting microbial proliferation, as previously observed by Mizzi et al. (2020). Pathogenic bacteria generally cannot grow below a water activity (aw) value of 0.85, while molds and yeasts are more tolerant, with microbial growth typically ceasing below 0.62 aw (Hocking & Pitt, 1979; Scott, 1953). Most halophilic bacteria and mycotoxigenic *Aspergillus* species can grow in the range of 0.80–0.75 aw but are inhibited at the minimum value of 0.75 aw. Bacteria, except for highly or moderately halophilic types, struggle to survive in low aw (high osmotic) conditions. Foods with high sugar content create an environment favorable for osmophilic yeasts (Tapia et al., 2020). Comparing these findings to our results, where aw values ranged from 0.68 (Samples E and H) to 0.74 (Sample J), it is unlikely to support significant microbial proliferation. However, the high total sugar concentration in these samples can act as an antimicrobial agent (Mizzi et al., 2020).

DPPH Antioxidant Activity

Antioxidant activity, measured by DPPH radical scavenging, varied significantly ($P < 0.05$) between 72.58% (Sample A) and 83.9% (Sample C). The high antioxidant capacity is attributed to the phenolic and flavonoid compounds in dates, which interact with the hydrocolloid matrix to enhance product functionality (Ghnimi et al., 2017). These results indicate that date gummy candies have potential as functional foods with added health benefits.

Total Soluble Solids (TSS), Total and Reducing Sugar

TSS values ranged from 61.3°Brix (Sample E) to 75.4°Brix (Sample B), while total sugars and reducing sugars ranged from 50.15% (Sample L) to 63.4% (Sample A) and 42.35% (Sample D) to 53.77% (Sample G), respectively. The high TSS and sugar content are primarily due to the natural composition of dates and the addition of glucose syrup, which enhances, texture, and shelf life (Efe and Dawson, 2022). Reducing sugar content ranged from 42.36% (Sample D) to 53.77% (Sample G), while total sugar content varied from 50.15% (Sample L) to 63.4% (Sample A). Samples with higher sugar content, such as A and G, are likely to exhibit enhanced sweetness and textural firmness due to sugar's role in gel formation. Conversely, lower sugar levels, such as in Sample D, may lead to softer or less chewy textures. These differences may result from the type and number of sweeteners used in the formulations (Efe and Dawson, 2022).

The high moisture content of candies makes them highly susceptible to pathogenic microorganisms (Juhaniaková et al., 2014). However, as noted by Silliker (1968), the high sugar content in food products immobilizes the available water, making it inaccessible for microbial growth. Consequently, microbial activity is typically localized to areas where free moisture is present, with molds and yeasts being more predominant than bacteria under such conditions. Therefore, the addition of antimicrobial preservatives is crucial to ensure the product's safety and stability.

Effect of Sugars on Gel Formation

The concentration of sugar in confectionery gels influences the gelling properties of hydrocolloids. In polysaccharide gel systems, sugar reduces chain-chain associations, leading to a less aggregated structure. As a result, a higher critical concentration of gelling agent is required to achieve gel formation in high-sugar environments. Conversely, gelatin gels behave differently in the presence of sugar. Instead of reducing chain association, sugar increases gelatin chain interactions, strengthening the gel network. Sugars destabilize polysaccharide gels at concentrations of 40–60% but enhance gelatin gel networks at the same concentrations (Lemos et al., 2021). This phenomenon explains the robust texture and stability of date gummy candies, even with high sugar content.

Color analysis of date gummy candy

The color parameters of date gummy candies are presented in Table 6. The observed values for the color parameters are as follows:

- **L*** values ranged from 37.67 to 42.05, indicating a moderately dark appearance.

- This darkness is primarily due to the natural color of the date paste used in the formulations.
- **a*** values ranged from 9.15 to 11.2, signifying a moderate red component in the color. The red intensity is balanced and not overly pronounced.
- **b*** values ranged from 20.87 to 25.06, reflecting a slight yellowish component in the color.

All color parameters showed significant differences (P > 0.005) among treatments.

The visual observation of the samples revealed a dark reddish-brown hue with a slight yellow tint, as illustrated in Figure 5. This color profile aligns with the natural appearance of dates and contributes to the characteristic appeal of date-based products. The slight yellow tint, while noticeable, does not overpower the overall reddish-brown tone, ensuring a visually appealing product.

Table 5. The physiochemical properties of date gummy candies

Sample	pH	Moisture content %	Water activity	DPPH	TSS Brix	Reducing sugar %	Total sugar %
A	3.2^{a}	21.62^{a}	0.7^{ab}	66.18^{a}	75.1^{d}	51.79^{c}	63.4^{f}
B	3.3^{ab}	21.71^{a}	0.7^{ab}	75.93^{de}	75.4^{d}	44.21^{ab}	56.07^{cd}
C	3.3^{ab}	23.28^{a}	0.69^{ab}	87.03^{h}	73^{d}	50.25^{bc}	53.87^{b}
D	3.4^{abc}	22.17^{a}	0.72^{bc}	83.92^{g}	63.2^{abc}	42.36^{a}	55.17^{bcd}
E	3.5^{abc}	20.13^{a}	0.68^{a}	83.2^{g}	61.3^{a}	49.63^{bc}	55.52^{bcd}
F	3.5^{abc}	21.35^{a}	0.72^{bc}	77.28^{ef}	67.5^{c}	50.10^{bc}	56.61^{cde}
G	3.3^{ab}	19.34^{a}	0.7^{ab}	76.04^{de}	65.8^{abc}	53.77^{c}	58.22^{e}
H	3.4^{abc}	20.39^{a}	0.68^{a}	72.51^{b}	62.3^{ab}	47.61^{abc}	56.99^{de}
I	3.4^{abc}	22.67^{a}	0.71^{abc}	73.96^{bc}	64.6^{abc}	49.57^{bc}	53.86^{b}
J	3.7^{c}	22.03^{a}	0.74^{c}	78.73^{f}	65.0^{abc}	49.32^{bc}	54.94^{bc}
K	3.6^{bc}	20.14^{a}	0.7^{ab}	$77.8e^{f}$	65.9^{abc}	47.45^{abc}	55.2^{bcd}
L	3.5^{abc}	19.61^{a}	0.7^{ab}	74.69^{cd}	67.2^{bc}	49.78^{bc}	50.15^{a}

Different letters in the same column indicate a significant difference (P <0.05).

Table 6. Color parameters of different date gummy candies treatments

Sample	L*	a*	b*
A	42.05^{g}	10.79^{fg}	23.12^{f}
B	46.84^{h}	9.47^{b}	25.06^{g}
C	48.1^{i}	9.15^{a}	26.3^{h}
D	41.67^{f}	10.46^{de}	22.72^{d}
E	40.2^{d}	11.35^{j}	23.05^{e}
F	38.71^{b}	10.87^{gh}	21.87^{c}
G	40.5^{e}	10.77^{eg}	22.94^{e}
H	37.65^{a}	11.14^{i}	21.96^{c}
I	39.59^{c}	10.62^{ef}	22.78^{d}
J	37.67^{a}	10.32^{d}	21.53^{b}
K	39.63^{c}	11.02^{hi}	20.88^{a}
L	$40.4d^{e}$	9.94^{c}	20.87^{a}

Different letters in the same column indicate a significant difference (P <0.05)

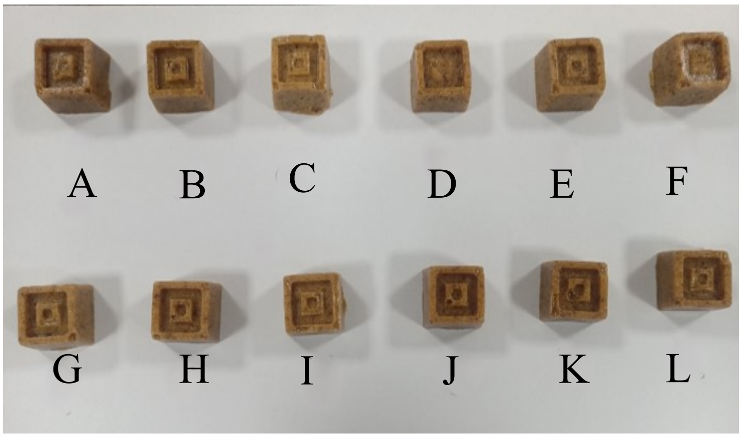


Figure 5. Different Treatments of Date-Based Gummy Candies

The observed changes in color parameters (**L***, **a***, and **b***) during the production of date gummy candies can be attributed to several factors:

Maillard Reactions

The mixing process at **85°C** likely initiated Maillard reactions between reducing sugars and amino acids, leading to the formation of browning compounds and contributing to the darker appearance of the final product (Kurt et al., 2021and Takeungwongtrakul et al., 2020).

Caramelization of Sugars

The application of heat during production caused caramelization, further darkening the product and enhancing its characteristic color.

Biochemical Changes in Natural Fruit Colors

Heat-induced biochemical reactions in the natural pigments of date pulp intensified the darker and opaque appearance of the candies. The incorporation of fiber from date pulp also contributed to this effect, as fiber is known to darken the overall appearance of food products (Mutlu et al., 2018; Figueroa and Genovese, 2019).

Sensory Evaluation

The sensory evaluation results for texture, chewing, odor, taste, color, and overall palatability are presented in Figure 6. There was a significant differences ($P < 0.05$) except for color, all sensory attributes showed significant variations among the treatments.

Overall Palatability

The highest overall palatability scores were recorded for samples L (8.8), G (8.7), I (8.5), and J (8.5), indicating that these formulations were the most preferred by evaluators. This evaluation underscores the influence of ingredient ratios and processing conditions on the sensory appeal of date gummy candies, with specific formulations standing out as highly palatable options.

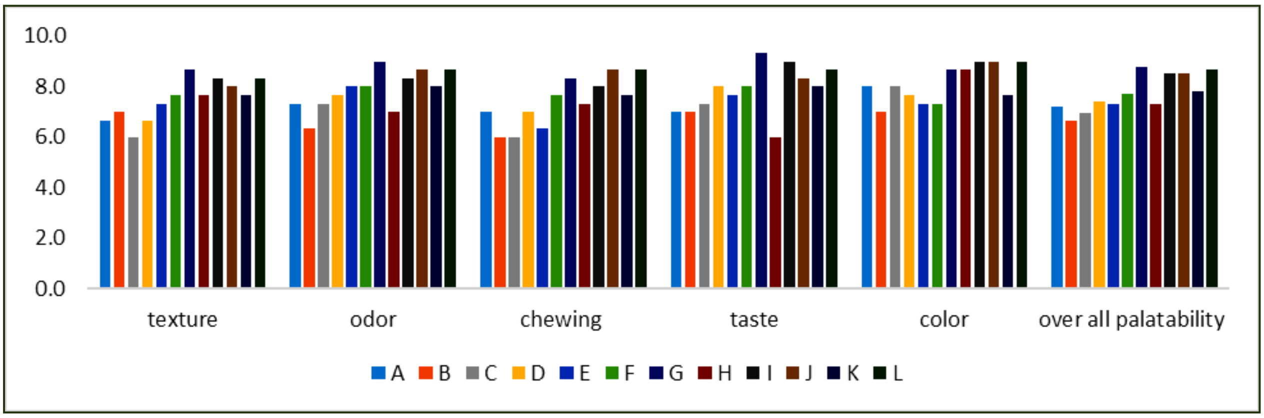


Figure 6. Sensory evaluation of date gummy candies with different treatments

4. Conclusions

This study demonstrated the successful development of date gummy candies by incorporating date paste and varying concentrations of gelatin and starch, alongside natural preservatives such as citric acid and cinnamon extract. The findings revealed that the formulations significantly influenced textural properties, such as gel strength, hardness, and cohesiveness, and enhancing flavor. The antimicrobial activity for both citric acid and cinnamon extract strengthen the safe consumption of the product. The gummy pastes exhibited pseudoplastic behavior favorable for industrial processing, and the final products showed excellent physicochemical stability, including optimal moisture content and water activity, supporting extended shelf life.

Moreover, the inclusion of date paste enriched the candies with higher antioxidant activity and improved sensory appeal, positioning them as functional foods with added health benefits. These results underline the potential of date gummy candies as a healthier and innovative alternative in the confectionery industry.

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