



Research Article

Shelf-Life Assessment and Prediction of *Gymnema inodorum* (Lour.) Decne. Jelly under Accelerated Storage Conditions

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ABSTRACT

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This study investigated changes in quality and shelf-life prediction of *Gymnema inodorum* jelly (GIJ) under accelerated storage conditions using the Q₁₀ model. The GIJ samples were stored at four controlled temperatures (4, 25, 35, and 45 °C) for 10 weeks to evaluate quality deterioration. Quality attributes, including color parameters (L*, a*, b*), syneresis, texture profile analysis (hardness, springiness, gumminess, and chewiness), microbiological quality, and sensory acceptability, were periodically assessed. Storage temperature and duration significantly influenced product quality, with progressive color degradation, increased syneresis, and reduced textural properties observed during prolonged storage, particularly at elevated temperatures. Microbiological analysis showed that total viable counts exceeded acceptable limits earlier at higher storage temperatures, reaching the regulatory threshold at weeks 4 and 6 under storage at 45 °C and 35 °C, respectively. Sensory evaluation showed that the product remained acceptable during the initial storage period, with liking scores above the predefined acceptance threshold, but declined progressively with extended storage. Shelf-life prediction based on the Q₁₀ model estimated that GIJ could be stored for approximately 147.6 days (4 months and 27 days) at 4 °C and 63 days (2 months and 3 days) at 25 °C. Under these conditions, the product remained acceptable to consumers and complied with the Thai Community Product Standard (TCPS 519/2547). These findings demonstrate the applicability of the Q₁₀ model as a practical tool for predicting the storage stability of functional jelly products while supporting product development, quality control, and commercialization.

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1. Introduction

The development of ready-to-eat functional foods derived from local medicinal plants has gained increasing attention due to their potential to add value to agricultural raw materials while meeting the growing consumer demand for health-promoting products. *Gymnema inodorum* (Lour.) Decne (*G. inodorum*), an indigenous plant widely consumed in Southeast Asia, is rich in bioactive compounds, particularly phenolic compounds, flavonoids, and gymnemic acids. These phytochemicals exhibit strong antioxidant properties and have been reported to contribute to glycemic control and other health benefits (Tiwari *et al.*, 2014; Tiomyom *et al.*, 2019; Dunkhunthod *et al.*, 2021;

Nunta *et al.*, 2023). Consequently, *G. inodorum* has considerable potential for application in various functional food products, including beverages, snacks, and gel-based confectionery.

Jelly products are among the most popular semi-solid foods due to their soft texture, ease of chewing, and high consumer acceptability across different age groups. Their structure is formed by a three-dimensional polymeric gel network capable of retaining a large amount of water, resulting in desirable sensory and textural characteristics (Chaurasia *et al.*, 2023; Baiti *et al.*, 2024). In recent years, plant-based functional jellies enriched with bioactive compounds from fruits, vegetables, and medicinal plants have gained increasing attention because of their potential health benefits. However, these products often

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exhibit greater formulation complexity due to interactions between bioactive constituents and hydrocolloid networks, which may affect gel stability during storage. In addition, jelly systems typically contain high moisture levels, hydrocolloids, and sugars, which make them susceptible to physical, chemical, and microbiological changes during storage. One of the most common quality defects is syneresis, a phenomenon in which contraction of the polymer network expels water from the gel matrix, leading to reduced firmness and overall product deterioration. In addition, gel softening and microbial growth may occur, further compromising product quality and safety (Arslan and Kadagan, 2021; Arab *et al.*, 2022; Lin *et al.*, 2023). These changes can negatively affect consumer acceptance and shorten the product's shelf life.

Although food processing can extend product stability, quality degradation and spoilage may still occur during storage. Therefore, shelf-life evaluation is a critical step in food product development, as it determines the period during which a product maintains acceptable quality, safety, and sensory attributes. Accurate shelf-life estimation is also an essential component of good manufacturing practices (Suwan and Suwannakam, 2021). Furthermore, food regulations require manufacturers to clearly declare expiration dates or "best before" information on product labels (Ministry of Public Health, 2024). Conventional shelf-life testing under normal storage conditions can be time-consuming and costly, especially for products with extended stability. Accelerated storage testing offers a practical alternative, as elevated temperatures can hasten physical, chemical, and microbiological deterioration, enabling faster prediction of product stability (Sinhaipanit *et al.*, 2022). Among predictive approaches, the Q_{10} model is widely used to estimate shelf life based on the relationship between temperature and reaction rate, assuming that the deterioration rate increases with increasing storage temperature. This approach enables rapid prediction of product stability under normal storage conditions using data obtained from accelerated storage studies (Arboretti *et al.*, 2022; Xiao *et al.*, 2022).

Despite the growing interest in *G. inodorum* as a functional food ingredient, studies on the storage stability and shelf-life of products developed from this plant remain limited. Therefore, this study aimed to investigate the quality changes of *G. inodorum* jelly (GIJ) during accelerated storage. The products were stored at 4, 25, 35, and 45 °C for 10 weeks, and changes in color parameters, texture profile analysis, syneresis, microbiological quality, and sensory acceptance were evaluated. The findings are expected to provide useful information for determining appropriate storage conditions and estimating the shelf life of the product to ensure quality and consumer safety.

2. Materials and Methods

2.1 Materials and chemicals

G. inodorum leaves were obtained from a local plantation in the Mae-On District of Chiang Mai Province, Thailand. Samples were collected between February and April 2024 without consideration of the specific season or time of collection. The first three pairs of young leaves from the apical regions of the plants were harvested. Carrageenan and konjac powder (food-grade) were purchased from Yok Intertrade (Chiang Mai) Co., Ltd. Citric acid (food-grade) was acquired from Specialfood (Samut Prakan) Co., Ltd. Monk fruit syrup was purchased from Miss Cony, Thailand. 3M™ Petrifilm™ aerobic count plate and 3M™ Petrifilm™ yeast and mold count plate were acquired from 3M company (MN, USA). Peptone was obtained from HiMedia Laboratories Pvt. Ltd. (Nashik, India). Purified water was produced using a Millipore water purification system (Millipore, Bedford, MA, USA).

2.2 Study on quality changes of GIJ products during accelerated storage

Aqueous *G. inodorum* leaf extract was prepared with slight modifications to the method described by Banpacha *et al.* (2025). Briefly, dried *G. inodorum* leaves were weighed and mixed with clean drinking water at 50 °C to obtain a 3% (w/v) concentration. The extraction was carried out for 3 min, after which the mixtures were filtered through a tea filter bag to remove solid residues and allowed to cool to room temperature before use.

For jelly preparation, K-carrageenan and konjac flour were blended at a ratio of 1:1 and incorporated into the aqueous *G. inodorum* leaf extract at a total hydrocolloid concentration of 1.5% (w/v). The selected ratio was based on previous studies reporting improved gel strength, chewiness, and structural stability due to synergistic interactions between K-carrageenan and konjac gum, with the 1:1 ratio identified as optimal for desirable gel characteristics (Tunieva *et al.*, 2021; Wang *et al.*, 2021). The mixture was allowed to hydrate for 5 min. Monk fruit syrup (12.2%, w/v) was added, and the solution was heated to 85 ± 2 °C with continuous stirring for 10 min to ensure complete dissolution and homogeneity. Heating was discontinued, and citric acid (0.3%, w/v) was added to adjust the formulation. The hot jelly solution was immediately filled into aluminum foil sachets (12 g) and hermetically sealed. Freshly prepared samples were analyzed on day 0 to determine the initial microbial load before storage. Subsequently, the products were stored at controlled temperatures of 4, 25, 35, and 45 °C under laboratory conditions (approximately 65% RH) for 10 weeks. Samples were withdrawn at two-week intervals for quality evaluation.

2.3 Color measurement

Color characteristics were determined using the CIE L^* , a^* , b^* color system with a HunterLab ColorFlex EZ colorimeter (USA). The parameters recorded included lightness (L^*),

redness/greenness (a^*), and yellowness/blueness (b^*), and the average values were reported.

The total color difference (ΔE^*) was calculated to evaluate overall color changes during storage according to the following equation:

$$\Delta E^* = \{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2\}^{1/2} \quad (1)$$

where ΔL^* , Δa^* , and Δb^* represent the differences between the initial color values (L_1 , a_1 , b_1) and the measured color values at each storage time (L_2 , a_2 , b_2), respectively.

2.4 Syneresis of GIJ products during accelerated storage

Syneresis was determined according to the method of Saraboot *et al.* (2018) with slight modifications. Jelly samples (5 g) were weighed and placed on Whatman No. 4 filter paper positioned on a wire mesh screen. The samples were allowed to drain at their respective storage temperatures for 2 h. The syneresis was calculated using the following equation.

$$\text{Syneresis (\%)} = \frac{\text{Total weight of separated liquid (g)}}{\text{Total weight of sample (g)}} \times 100 \quad (2)$$

2.5 Texture profile analysis (TPA) of GIJ products during accelerated storage

The TPA (hardness, springiness, gumminess, and chewiness) was performed according to the method described by Kaewpetch *et al.* (2024) with six replications. Measurements were conducted using a texture analyzer (TA.XT plus, Stable Micro System, Surrey, UK) equipped with a P/50 cylinder probe (50 mm diameter). Samples were subjected to two consecutive compression cycles with a 3 s interval between compressions to simulate mastication. The operating parameters were set as follows: pre-test speed of 1 mm/s, test speed of 5 mm/s, post-test speed of 5 mm/s, a strain of 75%, and a trigger force of 5 g.

2.6 Microbiological analysis

Microbiological quality was evaluated throughout storage at 4, 25, 35, and 45 °C. Total viable count (TVC) and yeast and mold (YM) populations were determined according to the methods described by 3M Food Safety (2021) and Schumacher *et al.* (2023) using 3M™ Petrifilm™ plates (3M Company, St. Paul, MN, USA). At each sampling interval, a 10 g portion of sample was aseptically weighed and homogenized with 90 mL of sterile 0.1% peptone water to obtain an initial dilution of 10^{-1} . A decimal dilution series (10^{-1} to 10^{-6}) was subsequently prepared using the same diluent. For enumeration, 1 mL of each dilution was dispensed onto the center of 3M™ Petrifilm™ Aerobic Count plates for TVC and 3M™ Petrifilm™ Yeast and Mold plates. The inoculum was evenly distributed using a sterile plastic spreader and was allowed to solidify for 1 min prior to incubation. All plates were incubated in a calibrated incubator (Gallenkamp, Model: SIZE TWO, UK). Aerobic count plates were incubated at 35 ± 1 °C for 48 ± 3 h, whereas YM plates were incubated at 25 ± 1 °C for 3–5 days. Following incubation,

colonies were enumerated according to the manufacturer's interpretation guidelines. Plates containing 25–250 colonies for TVC and fewer than 150 colonies for YM were selected for counting. All analyses were performed in triplicate, and microbial populations were calculated and expressed as colony-forming units per gram of sample (CFU/g).

2.7 Sensory evaluation of GIJ products during accelerated storage

Sensory evaluation was conducted using an untrained panel consisting of 60 participants (38 females and 22 males) aged between 20 and 60 years, who were recruited from Chiang Mai Province, Thailand. This study was approved by the Ethics Committee of Chiang Mai University (approval number: CMUREC 67/071). Written informed consent was obtained from all participants prior to their involvement in the study. Samples were coded by three-digit random numbers and were served in a randomized order determined by random permutation. Distilled water was provided, and panelists were instructed to cleanse their palate between samples (Godoy *et al.*, 2013). Participants rated each sample for degree of liking using 9-point hedonic scales, ranging from 1 (dislike extremely) to 9 (like extremely) (Meilgaard *et al.*, 2025). Sensory attributes included appearance, color, aroma, flavor, sweetness, sourness, texture, and overall acceptability.

2.8 Determination of quality indices and accelerated shelf-life estimation

2.8.1 End-of-shelf-life criteria

Quality indices representing both product safety and consumer acceptance were established to determine the end of shelf-life. Critical limits (cut-points) were defined based on microbiological safety standards and sensory acceptability criteria.

(1) Microbiological criteria: Microbiological quality was considered the primary criterion for shelf-life determination because consumer safety is a mandatory requirement and microbiological deterioration represents an irreversible quality defect. Microbiological limits were established in accordance with the Community Product Standard for soft jelly issued by the Thai Community Product Standard (TCPS 519/2547). The maximum allowable limits were set at $\leq 1 \times 10^4$ CFU/g for TVC and ≤ 100 CFU/g for YM.

(2) Sensory acceptability criteria: Consumer acceptance was determined based on sensory liking scores obtained using a nine-point hedonic scale. The cut-point was defined as a mean score lower than 6 ("like slightly"), below which the product was considered unacceptable to consumers.

Shelf-life was defined as the earliest time point at which either microbiological or sensory criteria exceeded the predefined cut-point.

2.8.2 Accelerated shelf-life estimation using the Q_{10} method

Shelf-life under accelerated storage conditions was estimated using the Q_{10} method, which is widely applied for predicting the shelf-life of food products based on the effect of

temperature on the rate of quality deterioration. The Q_{10} value represents the factor by which the rate of a chemical or physical reaction increases when the temperature is raised by 10 °C. This approach is based on the principle that temperature influences reaction rates, as higher temperatures increase the kinetic energy of molecules, causing them to move more rapidly and collide more frequently. Consequently, the rate of chemical reactions and quality deterioration increases compared with that at lower temperatures (Sinchaipanit *et al.*, 2022).

In this study, accelerated storage tests were conducted at 35 and 45 °C to obtain deterioration data, while shelf-life at 4 and 25 °C was predicted based on the temperature dependence of quality loss. The Q_{10} value was calculated using the following equation:

$$Q_{10} = \frac{\theta_{S(T)}}{\theta_{S(T+10)}} \quad (3)$$

where $\theta_{S(T)}$ and $\theta_{S(T+10)}$ represent the estimated shelf-life at temperatures T and T+10, respectively. The temperature coefficient for a 1 °C temperature difference was calculated as:

$$Q_1 = Q_{10}^{0.1} \quad (4)$$

where Q_1 represents the temperature coefficient for a 1 °C change in storage temperature. For temperature differences other than 10 °C, the temperature coefficient was calculated using:

$$Q^{\Delta T} = \frac{\theta_{S(T)}}{\theta_{S(T+\Delta T)}} \quad (5)$$

where $Q^{\Delta T}$ represents the temperature coefficient for a temperature difference of ΔT °C, and ΔT represents the difference between the two storage temperatures.

Shelf-life was defined as the earliest time point at which either microbiological counts exceeded the regulatory limits or sensory scores fell below the predefined acceptance threshold.

2.9 Statistical analysis

Physical properties were analyzed in triplicate, while texture measurements were performed in six replicates for each treatment. SPSS statistics 17.0 (SPSS Inc., Chicago, IL, USA) was used to calculate means, standard deviations (SD), and to perform multivariate analysis. Duncan's multiple range test was used to determine significant differences at a 95% confidence level ($p < 0.05$).

3. Results and Discussion

3.1 Effect of accelerated storage temperature on quality changes of GIJ

3.1.1 Changes in color parameters

Shelf-life evaluation of GIJ products was conducted under accelerated storage conditions at 4, 25, 35, and 45 °C for

10 weeks. The color parameters of the products were evaluated using the CIE color system (Figure 1). The L^* value, representing lightness, ranged from 82.35 to 82.47 (Figure 1a). The a^* value ranged from 1.80 to 2.44, with positive values indicating a red hue (Figure 1b), while the b^* value ranged from 39.45 to 42.44, with positive values indicating a yellow hue (Figure 1c). During storage, noticeable changes in color parameters were observed compared to the initial samples. This was consistent with the total color difference (ΔE^*), which progressively increased throughout the storage period in all treatments, ranging from 0.46 to 3.06 (Figure 1d). In general, ΔE^* values below 1.5 are considered imperceptible to the naked eye, values between 1.5 and 3.0 are noticeable but generally acceptable, and values greater than 3.0 indicate distinct color differences that may affect consumer acceptance (Chheng *et al.*, 2025).

A statistically significant decrease in L^* values ($p < 0.05$) was observed from week 6 onward, indicating a gradual darkening of the product. This trend is consistent with the findings of Kamil *et al.* (2023), who reported reduced lightness in probiotic gummy candies during storage. Although no significant differences were detected within the first 4 weeks, a decreasing trend in lightness was still evident, suggesting that early-stage color degradation had begun prior to reaching statistical significance. Similarly, the redness (a^*) and yellowness (b^*) values showed significant decreasing trends ($p < 0.05$) throughout the storage period, indicating a reduction in redness and yellowness intensity. Collectively, these results demonstrate a progressive fading and darkening of the jelly product during storage. This change may be attributed to the presence of water-soluble phenolic and flavonoid pigments in the product (Goławska *et al.*, 2023). Prolonged storage may reduce the water-holding capacity of the gel matrix, leading to moisture migration and surface water exudation. Consequently, these pigments may dissolve and migrate with the released moisture to the product surface, resulting in reduced color intensity. In addition, elevated storage temperatures may accelerate chemical reactions such as oxidation and non-enzymatic browning, further contributing to color deterioration. Similar reductions in lightness and overall color intensity during storage have been reported in guava–pineapple jelly (Molla *et al.*, 2022), supporting the hypothesis that thermal exposure and storage duration are critical factors governing color stability in gel-based fruit products.

3.1.2 Changes in syneresis

Regarding gel structural stability, syneresis was used as an indicator of the amount of water released from the gel network during storage. The results showed that syneresis significantly increased ($p < 0.05$) with prolonged storage time (Figure 2), indicating progressive destabilization of the gel matrix. This finding is consistent with the report of Na Ayutthaya and Putduang (2016). The increase in syneresis can be attributed to the contraction of the three-dimensional gel network

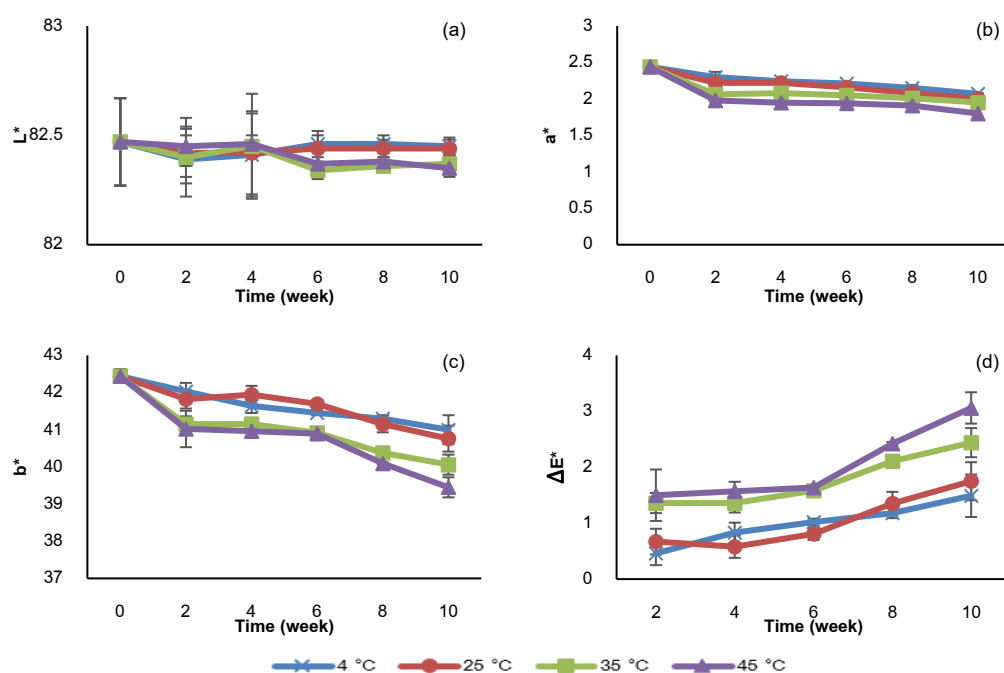


Figure 1 Changes in CIE L* (a), a* (b), b* (c) values and total color difference (ΔE^*) (d) of GIJ during storage at different temperatures for 10 weeks.

structure, which exerts pressure on the entrapped water and forces it out of the gel matrix (Arab *et al.*, 2023). In addition, elevated storage temperatures may accelerate molecular movement and weaken intermolecular interactions within the gel structure, thereby reducing water-holding capacity and promoting phase separation (Chen *et al.*, 2025). These structural changes may adversely affect overall product quality, particularly texture acceptability and visual appearance, due to visible water separation in the jelly product. Excessive syneresis has also been associated with reduced physical stability and shorter shelf life of gel-based food products during storage (Mizrahi, 2010; Petcharat *et al.*, 2026).

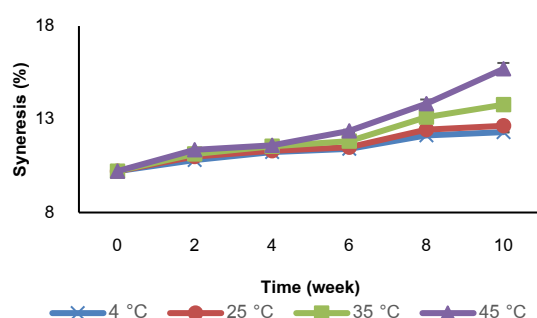


Figure 2 Changes in syneresis of GIJ during storage at different temperatures for 10 weeks.

3.1.3 Changes in TPA

The changes in textural properties of GIJ products during accelerated storage at 4, 25, 35, and 45 °C for 10 weeks were evaluated. The results demonstrated that texture

parameters, including hardness, springiness, gumminess, and chewiness, significantly decreased ($p < 0.05$) with increasing storage time (Figure 3). These findings indicate that the jelly gel became progressively softer during storage. The softening behavior can be attributed to the deterioration of the gel structure over time. The three-dimensional polymeric network of the gel tends to contract during storage, causing the entrapped water to be expelled from the gel matrix. This effect is more pronounced at elevated temperatures, which accelerate syneresis, defined as water separation from the gel network. Consequently, structural density decreases, intermolecular interactions weaken, and the mechanical strength of the gel is reduced (Na Ayutthaya and Putduang, 2016; Lin *et al.*, 2025). Similar decreases in hardness, gumminess, and chewiness during storage were reported by Chheng *et al.* (2025) in Sesban flower extract jelly. The deterioration of textural properties may negatively affect product quality and consumer acceptability, particularly in terms of chewiness and gel consistency, and may ultimately limit the shelf life of the jelly product.

3.1.4 Microbiological properties

The microbiological quality of the jelly products during storage at 4, 25, 35, and 45 °C for 10 weeks is presented in Table 1. TVC and YM counts were evaluated and compared with the Thai Community Product Standard (TCPS. 519/2547), which specifies limits of not more than 1×10^4 CFU/g for total microorganisms and not more than 100 CFU/g for YM.

For TVC, the initial samples and those stored during the early weeks at all temperatures exhibited counts below 10 CFU/g, reflecting satisfactory hygienic quality and appropriate

manufacturing practices. However, with prolonged storage, particularly at elevated temperatures, a marked increase in microbial growth was observed. At 45 °C, TVC exceeded the regulatory limit by week 4 (1.7×10^4 CFU/g). Similarly, samples stored at 35 °C surpassed the permissible level by week 6 (1.3×10^4 CFU/g), while those stored at 25 °C exceeded the standard by week 10 (2.5×10^4 CFU/g). In contrast, samples stored at 4 °C remained within the acceptable limit throughout the storage period. These results indicate that TVC was the primary factor limiting product shelf life, as it was the first quality parameter to reach unacceptable levels under accelerated storage conditions. YM counts also increased gradually during storage; however, all values remained below the regulatory threshold throughout the experiment. The accelerated increase in TVC at higher storage temperatures can be attributed to enhanced microbial metabolic activity and faster rates of cell division under favorable thermal conditions (Qiu *et al.*, 2022). Moreover, the microbiological changes were closely associated with the physical deterioration of the jelly matrix observed during storage. As storage temperature increased, degradation of the gel network and greater syneresis were observed, leading to the release of free water from the gel structure. The increased availability of surface moisture may have created a more favorable environment for microbial growth. Therefore, the reduced microbiological stability of the jelly at elevated temperatures was likely the combined result of temperature-induced stimulation of microbial activity and temperature-related deterioration of the gel structure, which enhanced water availability through syneresis (Tarlak, 2023).

3.1.5 Sensory evaluation

Sensory evaluation was conducted using a 9-point hedonic scale to assess consumer preference in terms of appearance, color, aroma, flavor, sweetness, sourness, texture, and overall acceptability. The results showed that GIJ products received liking scores ranging from 6.1 to 7.9 across all attributes during storage, corresponding to “like slightly” to “like very much,” as presented in Table 2. The symbol “—” in the table indicates time points at which sensory evaluation was not performed. This was due to microbial counts exceeding the limits specified by the Thai Community Product Standard No. 519/2547 ($\text{TVC} \leq 1 \times 10^4$ CFU/g and $\text{YM} \leq 100$ CFU/g). Sensory testing was therefore discontinued at those time points to ensure panelist safety. Consequently, sensory evaluation was conducted only for samples that met the microbiological safety criteria. Overall, the GIJ products maintained acceptable sensory quality during the early stages of storage. The relatively high scores for appearance and color suggest that the appearance characteristics of the jelly were well maintained, which is an important factor influencing consumer purchase intention. However, a gradual decline in sensory attributes was observed as storage progressed, which may be associated with physicochemical and microbiological changes occurring in the product. Changes in texture could be related to moisture migration or structural modifications in the gel network (Lin *et al.*, 2025), while slight reductions in aroma and flavor may result from the degradation or volatilization of flavor compounds during storage. These findings are consistent with the study of Putri *et al.* (2025), who reported a significant decline in consumer liking scores for jelly products during storage. Their study also indicated that storage at 25 °C accelerated quality deterioration compared with storage at 4 °C.

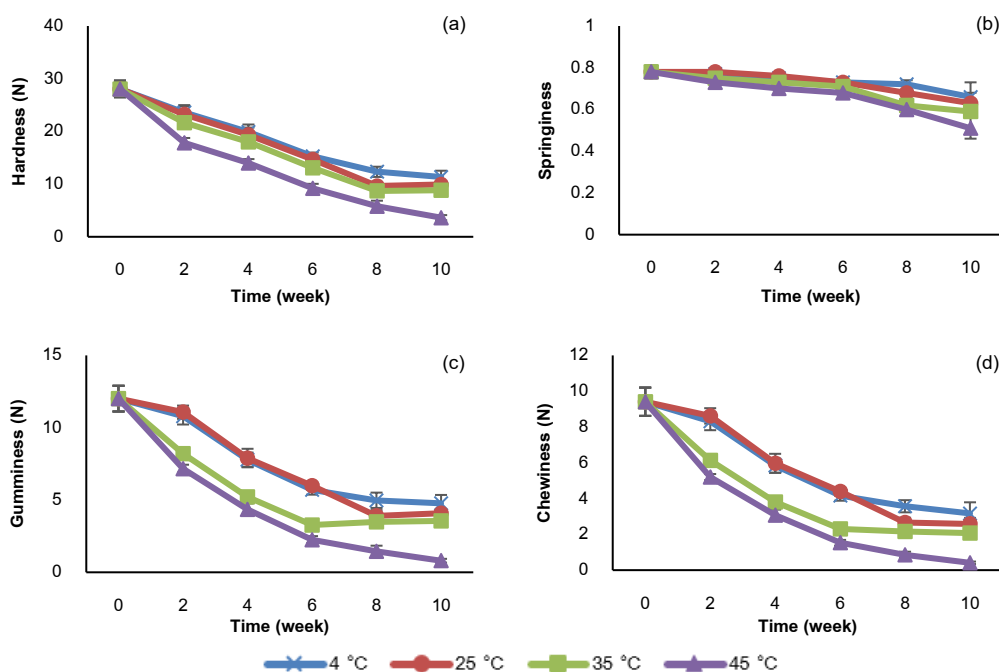


Figure 3 Changes in hardness (a), springiness (b), gumminess (c), and chewiness (d) of GIJ during storage at different temperatures for 10 weeks.

Table 1 Microbial growth of TVC and YM counts in GIJ during storage at different temperatures for 10 weeks.

Properties	Storage temperature (°C)	Storage time (weeks)					
		0	2	4	6	8	10
TVC (CFU/g)	4		<10	<10	<10	3.0×10^1	1.4×10^2
	25	<10	<10	<10	1.3×10^1	5.7×10^2	2.5×10^4
	35		<10	4.5×10^2	1.3×10^4	4.5×10^5	2.8×10^6
	45		2.8×10^2	1.7×10^4	2.3×10^5	6.7×10^5	2.4×10^6
YM (CFU/g)	4		<10	<10	<10	<10	<10
	25	<10	<10	<10	<10	4.7×10^1	8.9×10^1
	35		<10	<10	<10	<10	3.2×10^1
	45		<10	<10	<10	<10	1.2×10^1

Table 2 Sensory evaluation of GIJ during storage at different temperatures for 10 weeks.

Sensory attributes	Storage temperature (°C)	Storage time (weeks)					
		0	2	4	6	8	10
Appearance	4		7.7 ± 0.5	7.6 ± 0.8	7.6 ± 0.5	7.6 ± 0.5	7.3 ± 0.8
	25	7.8 ± 0.4	7.6 ± 0.8	7.6 ± 0.7	7.5 ± 0.5	7.2 ± 0.6	-
	35		7.5 ± 0.7	7.5 ± 0.9	-	-	-
	45		7.6 ± 0.5	-	-	-	-
Color	4		7.6 ± 0.7	7.5 ± 0.7	7.5 ± 0.5	7.4 ± 0.5	7.3 ± 0.8
	25	7.8 ± 0.4	7.7 ± 0.9	7.7 ± 0.8	7.5 ± 0.5	7.2 ± 0.6	-
	35		7.7 ± 0.7	7.7 ± 0.7	-	-	-
	45		7.6 ± 0.5	-	-	-	-
Aroma	4		6.6 ± 1.2	6.6 ± 0.8	6.5 ± 0.5	6.3 ± 0.8	6.2 ± 0.8
	25	6.5 ± 1.0	6.6 ± 1.2	6.5 ± 0.9	6.6 ± 0.5	6.4 ± 0.7	-
	35		6.1 ± 1.2	6.4 ± 0.7	-	-	-
	45		6.0 ± 0.9	-	-	-	-
Flavor	4		7.6 ± 1.0	7.3 ± 0.5	7.3 ± 0.5	7.1 ± 0.7	6.9 ± 1.1
	25	7.5 ± 0.9	7.7 ± 0.5	7.1 ± 1.0	7.0 ± 0.8	7.0 ± 0.8	-
	35		7.3 ± 0.5	6.9 ± 0.6	-	-	-
	45		7.3 ± 0.7	-	-	-	-
Sweetness	4		7.6 ± 0.8	7.4 ± 0.7	7.3 ± 0.7	7.3 ± 0.9	7.0 ± 0.9
	25	7.5 ± 0.9	7.6 ± 0.5	7.3 ± 0.5	7.2 ± 0.4	7.1 ± 0.7	-
	35		7.0 ± 1.1	6.9 ± 0.6	-	-	-
	45		7.1 ± 0.9	-	-	-	-
Sourness	4		6.7 ± 0.9	6.7 ± 0.7	6.6 ± 0.5	6.4 ± 0.7	6.1 ± 0.7
	25	6.8 ± 0.6	6.6 ± 1.1	6.7 ± 0.5	6.6 ± 0.8	6.5 ± 0.7	-
	35		6.3 ± 1.5	6.6 ± 0.7	-	-	-
	45		6.3 ± 0.8	-	-	-	-
Texture	4		7.9 ± 0.7	7.5 ± 0.5	7.2 ± 0.8	7.2 ± 0.4	6.8 ± 0.6
	25	7.8 ± 0.8	7.9 ± 0.6	7.7 ± 0.5	7.1 ± 1.0	7.1 ± 0.7	-
	35		7.2 ± 0.9	7.4 ± 0.7	-	-	-
	45		6.8 ± 0.9	-	-	-	-
Overall liking	4		7.7 ± 0.9	7.7 ± 0.7	7.6 ± 0.7	7.4 ± 0.7	6.9 ± 0.7
	25	7.9 ± 0.7	7.6 ± 0.5	7.6 ± 0.5	7.5 ± 0.5	7.3 ± 0.8	-
	35		7.2 ± 0.6	7.3 ± 0.5	-	-	-
	45		7.2 ± 0.8	-	-	-	-

Note: Each value represents the mean $\pm$ SD (n = 60)

3.2 Shelf-life prediction of GIJ under accelerated storage conditions

Based on the evaluation of GIJ product quality during 10 weeks of storage, changes in physical, microbiological, and sensory attributes were observed, indicating gradual product deterioration. The end-of-shelf-life criteria (cut-point) were defined based on the limits specified by the Thai Community Product Standard No. 519/2547, namely $TVC \leq 1 \times 10^4$ CFU/g and $YM \leq 100$ CFU/g, and/or a sensory acceptability score of less than 6 on the 9-point hedonic scale. The results showed that the microbiological limit was reached earlier than the sensory acceptability limit. Therefore, the microbiological criterion was used to determine the shelf-life of the product.

Under storage at 35 °C, the shelf life of the GIJ product was determined to be 6 weeks (42 days), whereas at 45 °C, the shelf life was limited to 4 weeks (28 days), based on the defined cut-point criteria. These data were subsequently used to calculate the Q_{10} value and to estimate the shelf life at 4 °C ($\theta_{S(4)}$). The predicted shelf life at 4 °C was 147.6 days (approximately 4 months and 27 days), as calculated below.

$$Q_{10} = \frac{\theta_{S(T)}}{\theta_{S(T+10)}} = \frac{\theta_{S(35)}}{\theta_{S(45)}} = \frac{42}{28} = 1.5$$

$$Q_1 = Q_{10}^{0.1} = 1.5^{0.1} = 1.04138$$

$$Q^{\Delta T} = Q_1^{35-4} = 1.04138^{31} = \frac{\theta_{S(4)}}{\theta_{S(35)}} = \frac{\theta_{S(4)}}{42}$$

$$\theta_{S(4)} = 1.04138^{31} \times 42 = 147.6$$

Furthermore, the predicted shelf life at 25 °C ($\theta_{S(25)}$) was estimated to be 63 days (approximately 2 months and 3 days), as calculated below.

$$Q^{\Delta T} = Q_1^{35-25} = 1.04138^{10} = \frac{\theta_{S(25)}}{\theta_{S(35)}} = \frac{\theta_{S(25)}}{42}$$

$$\theta_{S(25)} = 1.04138^{10} \times 42 = 63.0$$

The shelf-life values determined at 35 and 45 °C were used as accelerated storage data for the development of the Q_{10} prediction model. Subsequently, the shelf-life predicted by the model at 25 °C was validated using the actual storage data obtained at the same temperature. The predicted shelf-life showed good agreement with the observed shelf-life, as the product reached the end of its shelf-life between weeks 8 and 10 (approximately 62 days). This agreement suggests that the accelerated shelf-life testing approach combined with the Q_{10} model provided a reliable estimation of the product shelf-life. These findings are comparable with the study of Saloko *et al.* (2024), who reported that Moringa leaf jelly drink had a shelf-

life of approximately 4 months under refrigerated storage (10 °C) and about 2 months at room temperature (30 °C).

4. Conclusion

In the shelf-life study of GIJ products, the storage stability was predicted using the Q_{10} model. Total viable count was identified as the primary shelf-life limiting factor, as it was the first quality parameter to exceed the microbiological standard during storage. Product deterioration was accelerated at elevated temperatures due to the combined effects of increased microbial activity and degradation of the gel structure, which promoted syneresis and increased water availability for microbial growth. Based on the Q_{10} model, the predicted shelf-life of the product was approximately 147.6 days (4 months and 27 days) at 4 °C and 63 days (2 months and 3 days) at 25 °C. Under both storage conditions, the product maintained acceptable sensory quality and complied with microbiological safety standards throughout the predicted shelf-life period.

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