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The Effect of Honey and Habbatussauda (*Nigella sativa*) on the Storage and Gummy Stability

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Abstract— Gummy candy is a popular confectionery traditionally made with sugar, glucose syrups, gelling agents, acids, flavourings, and colouring agents. With health-conscious consumers seeking healthier alternatives, honey was chosen as a natural sugar substitute in this study, combined with Habbatussauda oil for its potential health benefits. The study evaluated the stability of these gummies under room temperature, chilled, and freezing conditions over six months. Results indicate that chilled storage is optimal for maintaining the quality of honey and Habbatussauda gummies for up to three months, with stable moisture content and water activity (19.13% to 26.94% moisture, 0.662 to 0.674 water activity). For colour preservation, chilled or frozen conditions are best, with lightness (L^* values) remaining stable for up to two months and minimal changes in redness (a^* values) and yellowness (b^* values). Texture Profile Analysis (TPA) showed that freezing maintained the best texture, with hardness ranging from 6,889.32 g to 7,672.78 g and springiness from 0.90 to 1.00. Chilled storage provided good quality for up to three months, with hardness increasing from 7,025.95 g to 9,435.46 g before decreasing. Freezing proved most effective, with enthalpy of gelatinization (ΔH_{gel}) increasing from 16.247 J/g to 19.600 J/g, indicating excellent thermal stability. Conversely, room temperature storage resulted in significant thermal degradation, with ΔH_{gel} dropping from 11.781 J/g to 5.605 J/g, showing it is less effective in preserving gummy stability.

Index Terms—Gummy, Honey, Habatussauda oil, Habatussauda seeds, Physicochemical analyses, Storage stability,

I. INTRODUCTION

Honey and Habbatussauda (also known as *Nigella sativa*) are believed to be beneficial for food preservation and stability. The main reason honey is important as a food preservative is its ability to kill bacteria naturally, whereas *Nigella sativa* contains many bioactive compounds with health benefits including thymoquinone. Studies have shown that mixing honey with Habbatussauda can improve food products' stability by preventing the growth of microorganisms and maintaining texture. This has been observed in research that indicated the combination of these ingredients could enhance storage characteristics especially in relation to gummy products' preservation process. Honey is primarily composed of sugars (mainly fructose and glucose), water, and a variety of bioactive compounds, including vitamins, minerals, and antioxidants. Its low moisture content, acidity (average pH of 3.9), and the presence of hydrogen peroxide contribute to its natural antimicrobial properties, making it an effective preservative that inhibits microbial growth and extends shelf life. Honey is widely used in the food industry not only for its sweetness but also for its health benefits, which include wound healing, anti-inflammatory effects, and potential support for respiratory and cardiovascular health. Additionally, honey can enhance the flavour, texture, and nutritional profile of various food products, including baked goods and beverages.

Habbatussauda, in the form of oil and powder, often known as black cumin or black seeds, is a spicy herb with medicinal properties [18]. It is native to a large area of the eastern Mediterranean, northern Africa, the Indian subcontinent, and Southwest Asia. Being a panacea, habbatussauda has been long recommended as a traditional medicine for a wide range of illnesses and conditions, including eczema, anorexia, amenorrhea, hypertension, rheumatism, headache, back pain, and paralysis [9]. A study done by Kooti *et al.* (2016) revealed that thymoquinone (TQ), thymohydroquinone, thymol, carvacrol, nigel-lidine, nigellicine, and hederin are the main compounds of black cumin seed, especially its essential oil, which are primarily accountable for its pharmacological effects and therapeutic advantages. habbatussauda, is rich in essential fatty acids, alkaloids, and flavonoids, with thymoquinone being its primary active component. This compound is known for its antioxidant, anti-inflammatory, and antimicrobial properties. Traditionally utilised in herbal medicine, habbatussauda is increasingly incorporated into food products for its health-promoting attributes and ability to enhance flavour. Its diverse bioactive compounds contribute to various health benefits, including improved immune function and potential anticancer effects.

Gummy candy is a popular type of sugar confectionery made through several steps: mixing, cooking, chilling, moulding, conditioning, demoulding, coating, and packaging [20][33]. The main ingredients in candy-making include gelling agents, sugar, corn syrup, and water [12]. Different candies need different cooking methods, gelling agents, and moisture levels. For example, hard candies usually have about 2% moisture, gelatine-based jellies about 22%, granular marshmallows around 12%, and Turkish delights about 20% [12]. Confectionery gels like gummies, jellies, and marshmallows are made from starch, gelatine, or pectin mixed with sugar and glucose syrup. [3] *et al.* (2009) note that while sugar is not part of the gel network, it plays a big role in forming these gels [15][16] found that gelatine and modified starch work together and gelatine makes the gels springy and clear, while starch imparts firmness and opacity. Gummies usually contain 5-10% gelatine, 16-21% moisture, and up to 75% sweeteners ([19] *et al.*, 2018). [5] and Bañón (2015) pointed out that to prevent mould growth, gummies need to have about 75% total soluble solids. Gummies are often exposed to heat during production, storage, and transportation, making it crucial to identify optimal formulations that maintain stability under varying temperature conditions. Thermal stability testing is essential for gummy candies, especially those with honey and habbatussauda, to ensure quality, safety, and shelf life. Differential Scanning Calorimetry (DSC) measures key thermal properties: onset, peak, and end temperatures. The onset temperature indicates when the gummy begins to melt or soften; a higher onset suggests better thermal stability. The peak temperature shows the point of maximum melting, affecting the gummy's texture and appearance. The end temperature marks the completion of the thermal transition, with higher values indicating the gummy can withstand heat longer without significant degradation ([15] [16] [17] [23].

Gummies are high in sugar, which can lead to health issues like obesity, tooth decay, and hyperglycaemia due to their high glycaemic index and calorie content [24]. To address these concerns, ongoing research aims to develop healthier candy options that maintain good taste, texture, and shelf life. This study seeks to create a healthier gummy by substituting sugar with Yemeni Sidr honey and adding Habbatussauda oil. Yemeni Sidr honey is rich in antioxidants and has potential health benefits, including anti-inflammatory, wound-healing, and antibacterial properties [1][31]. Despite the many gummy candies available, there is limited understanding of how they change during processing and storage. This study investigates how gummies with honey and Habbatussauda oil alter physically and chemically when stored at room temperature, in a chiller, and in a freezer over six months. Study done by Rivero found that gummies with honey and propolis change colour and antioxidant capacity (AC) over time, with minimal changes if stored in complete darkness for up to 45 days [29]. Factors such as moisture content, temperature, and preservatives affect gummy stability. Honey and Habbatussauda oil may enhance stability and shelf life, making the gummies more appealing to health-conscious consumers. This study analyses these changes to ensure product quality before market introduction.

II. MATERIALS AND METHOD

A. The Process of Gummy Development

The development of gummy candies (Figure 1.0) involves several key steps to ensure the final product meets the desired quality and texture. The process begins with the preparation of ingredients, which includes gathering gelatine, pectin, honey, citric acid, and Habbatussauda oil and powder. Firstly, the gelatine powder is soaked in water for 30 minutes to allow it to bloom. Following this, the bloomed gelatine is melted in a pan at 60°C. Once melted, honey is added and stirred until it is fully incorporated with the gelatine at a temperature of 90°C. Pectin powder is then gradually added while stirring continuously to prevent clumping. After achieving a uniform mixture, citric acid, Habbatussauda powder, and oil are incorporated while the temperature is increased. Next, the mixture is heated until it reaches a boiling state, at which point it is quickly poured into moulds. The filled moulds are placed in a chiller overnight to allow the gummies to set. The following day, corn starch powder is prepared in a bowl. After removing the moulds from the chiller, the gummies are demoulded and placed in the bowl with corn starch, where each gummy is evenly coated. Any excess corn starch is removed by sieving. Finally, the well-coated gummies are stored in a glass jar at room temperature. Throughout the entire process, careful monitoring and adjustments are made to maintain consistency and quality, ensuring the gummies meet specifications for size, shape, and texture before being packaged for distribution.

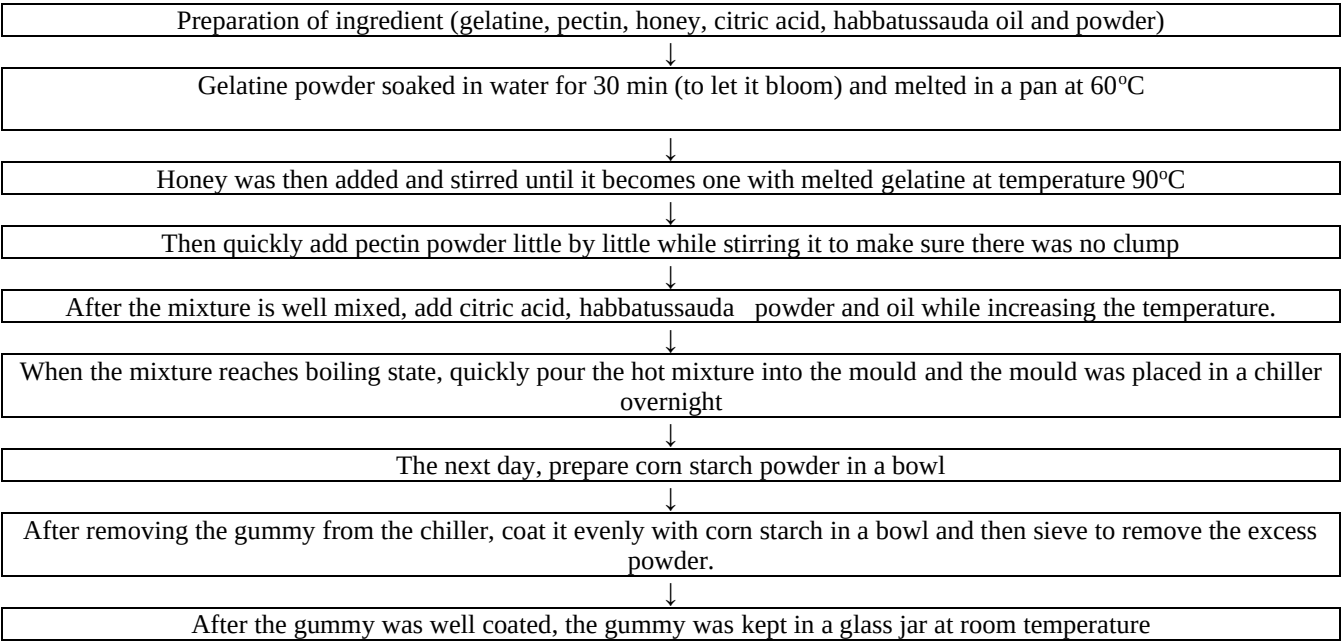


Figure 1.0: Processing Flow of Gummy Develop with Honey and Habbatussauda

There were 28 formulations were utilised in the development of honey and Habbatussauda gummies. The original composition consisted of gelatine, citric acid, honey, sugar, and glucose syrup whereby sugar and glucose syrup were substituted with honey. This substitution led to the alteration of water and gelatine ratio because of different moisture characteristics possessed in honey as compared to sugar or glucose syrup. On the other hand, the gummy formulations were also evaluated with varying proportions of Habbatussauda to enhance the flavour. Furthermore, the consistency of the gummies could be improved by using a combination of pectin and gelatine. The purpose of evaluating the gummy formulations with varying proportions of Habbatussauda is to determine the optimal amount that enhances the flavour while maintaining the desired taste and texture. Additionally, employing a combination of pectin and gelatine aims to improve the consistency and structural integrity of the gummies, ensuring they have the desired firmness and chewiness. This step is crucial for optimising the overall quality and consumer acceptability of the final gummy product.

After establishing the ideal characteristics of a perfect gummy, a coating of sugar syrup was applied using a 1:1 ratio of granulated sugar to corn starch. This method was employed during the iterative process of determining the optimal percentage of Habbatussauda to incorporate into the gummies. It was found that using a cornstarch-only coating effectively reduced the stickiness of the gummies compared to the sugar-cornstarch coating initially used. Ultimately, through careful formulation and effective coating techniques, the quality of the gummies was enhanced, ensuring their market appeal—a concept often referred to as "appeal" in marketing terminology. For the adjustment being done throughout all the formulation, personal preference and sensory evaluation done by random panel tasting was conducted. This helps to give a better understanding of the ingredients used and how consumers react to the combination of ingredients in developing the gummy. This also leads to the formation of a finalised gummy.

B. Preparation of Honey-Habbatussauda Gummy and Its Limitations

During this process of combining gelatine and pectin as a thickening agent in developing gummy, several formulations had been done to obtain the most preferred gummy structure. Several formulations were conducted to get the best structure by also evaluating it with panels via sensory evaluation. The aroma of Habbatussauda oil and powder in the gummy really gave slight negative feedback from panels who tried it due to not being familiar with its taste. This issue was overcome by adjusting the amount of honey and citric acid which camouflage the aroma of Habbatussauda.

C. Physicochemical Properties of Honey- Habbatussauda Gummy

Moisture content

The moisture of gummy samples was analysed according to the method described by and Yegge *et al.* (2021). A hand-held refractometer (Model TI-RBX4582/TI-RBX5890) that can determine between nD 1.3000–1.7200 and the soluble solid content in the range of 0–95 °Brix was used. This method measures the refractive index of the gummy solution, which correlates with moisture content. The refractive index can be converted to moisture content using the following equations;

$$\text{Moisture Content(\%)} = A \times (\text{Refractive Index}) + B$$

*where A and B are constants determined from calibration experiments with known moisture content samples.

Water activity (a_w)

Water activity was determined at 24–26°C using an electronic dew-point water activity metre Aqualab CX2 (Decagon Devices, Pullman, WA). The equipment was calibrated with saturated salt solutions in the water activity range of interest (Baeza *et al.*, 2010). For each determination, three replicates were obtained, and the average was reported.

Colour

The colour analysis of gummy samples was determined by using a Chroma metre (CR-400, Konica Minolta, Japan) and was expressed by L (lightness), a (redness), and b (yellowness) parameters in the CIELab system. The chroma metre was set at D65 illuminant and 10° standard observer and calibrated before each measurement against a standard white tile (Y = 93.8; x = 0.313; y = 0.319) (Salejda *et al.*, 2022). The samples were measured by placing it into a petri dish and placed on the sample's holder parallel to its base.

Texture Profile Analysis (TPA)

Texture profile analysis of gummy samples were performed using TA-XT 2 Texture metre (Texture Pro CT3 V1.2, Brookfield, Middleboro, USA) as described by Yuan and Chang (2007). Force time deformation curves were obtained during applying a 5 kg load cell, at a 1mm/s crosshead speed. The following texture attributes were calculated, hardness (g), adhesive force (g), resilience, fracturability (g) and springiness (mm).

Thermal Stability Testing

Based on the method by Silva de Azevedo and Zapata Norena (2021), the thermal stability of the gummy samples was measured using Differential Scanning Calorimetry (DSC) 8500 equipment (Perkin Elmer). Approximately 6 mg of the samples were weighed on an aluminium crucible, and the measurements were taken from 30°C to 150°C, at a heating rate of 10°C min⁻¹ with a nitrogen flow of 20 mL min⁻¹. Due to limited resources, the analysis was conducted without replication, and the data presented are based on a single experimental run.

III. RESULT AND DISCUSSION

A. Moisture content and water activity (a_w)

High moisture content can impact the internal molecular mobility or crystallisation/recrystallisation of formulation-related components [15] [16]. Table 1.0 shows the changes in moisture content may lead to undesirable alterations in stickiness, chewiness, and hardness parameters ([3] *et al.*, 2009). This is supported by [5], who found that the texture of sugar confections becomes harder as moisture content decreases. Trend observed for moisture content in room temperature storage, the moisture content remains relatively stable during the initial months, with minor fluctuations on the 5th month. However, there is a noticeable increase in the 6th month, reaching 26.94%. As for the chilled storage temperature, moisture content in gummy exhibits

Table 1.0 Moisture Water (%) And Activity (A_w) of Gummy Develop Using Honey and Habbatussauda in 6-Months Storage Durations

Mth	Moisture Content (%)			Water Activity (A_w)		
	Room	Chill	Freezer	Room	Chill	Freezer
1 st	18.28±0.37 ^{bD}	19.13±0.09 ^{aCD}	17.86±0.15 ^{bD}	0.677±0.04 ^{bABC}	0.682±0.001 ^{abA}	0.686±0.002 ^{aA}
2 nd	18.98±0.24 ^{aCD}	17.45±0.29 ^{bE}	19.77±0.71 ^{aC}	0.694±0.014 ^{aA}	0.680±0.004 ^{aA}	0.687±0.000 ^{aA}
3 rd	17.91±0.59 ^{bD}	18.89±0.13 ^{abD}	19.78±0.21 ^{aC}	0.664±0.010 ^{aC}	0.662±0.013 ^{aB}	0.667±0.002 ^{aAB}
4 th	22.14±0.40 ^{aB}	19.64±0.40 ^{bBC}	20.29±0.66 ^{bC}	0.687±0.002 ^{aAB}	0.675±0.005 ^{bAB}	0.674±0.003 ^{bAB}
5 th	19.88±0.53 ^{bC}	19.84±0.04 ^{bB}	21.61±0.02 ^{aB}	0.672±0.000 ^{aBC}	0.668±0.001 ^{aAB}	0.664±0.012 ^{aB}
6 th	26.74±0.59 ^{aA}	26.94±0.09 ^{aA}	26.75±0.57 ^{aA}	0.677±0.003 ^{aABC}	0.674±0.003 ^{aAB}	0.678±0.001 ^{aAB}

*Means within each row (a-c) and column (A-C) with different superscripts are significantly different at $p < 0.05$.

*Lower case letter indicates the effect of storage month and capital letter indicates the effect of storage temperature of gummy.

fluctuations over the four months, starting at 19.13% and experiencing a slight decrease by the 2nd month to 17.45%, then increasing significantly to 26.94% by the 6th month. Fluctuation in moisture content may lead to sugar crystallization within gummies. Thus, result in a grainy texture and affect the appearance and mouthfeel of the gummies. Also, gummy stored in freezing temperature, the moisture content starts relatively low but gradually increases over the 3 months, reaching a peak of 26.75% in the 6th month. Overall, the moisture content generally increases with time, especially in the later months, for all storage conditions. This increase is more pronounced in the 6th month [4].

More to the point, the water activity (A_w) in gummy demonstrates relatively stable behaviour across room temperature, chilled, and freezer conditions, with only minor fluctuations observed. At room temperature, the water activity starts at 0.677, slightly increases in the second month, dips to 0.664 by the third month, and then fluctuates slightly before returning to 0.677 by the sixth month. In chilled storage, water activity also shows minor fluctuations, beginning at 0.682, decreasing slightly to 0.662 by the third month, and stabilising around 0.674 by the sixth month. Under freezer conditions, water activity remains more consistent, ranging between 0.664 and 0.687 throughout the six months. Overall, the general trend indicates that water activity remains relatively stable under all storage conditions, with only slight variations. There was no significant difference observed which could be due to the reduced molecular mobility of water at lower temperatures, limiting changes in the availability of free water. The desirable water activity for gummies and jellies is between 0.50 to 0.75. Low water activity helps maintain gummy's chewy texture. Within this range it may prevent excess moisture to cause gelatine matrix to weaken and gummies become too soft or sticky. In line with the statement, gummy in this study has shown a desirable amount of a_w and the a_w above this range will allow the growth of yeasts, bacteria, and pathogens thus reducing the shelf life of confectionery gels [4][6].

Over time, moisture content increases especially on the 6 months storage conditions, which could be due to the hygroscopic nature of the product, absorbing moisture from the environment. Excess moisture content can lead to syneresis, where the liquid separates from the gel matrix causing the gummy to become watery and lose its structural

integrity. Despite the increase in moisture content, water activity remains relatively stable. This suggests that while the total water content is rising, the proportion of free water (which contributes to water activity) is not changing significantly. Stability of water activity may happen because the water might bind on to things like proteins or carbohydrates hence it does not contribute to free water that controls water activity. Also, cold and frozen storage conditions can keep water molecules in check from moving around too much hence little changes that occur in the level of water activity.

Notably, gummies stored at room temperature exhibited higher water activity levels compared to those stored in chilled and frozen conditions. This suggests that honey and habbatussauda may influence the moisture retention properties of the gummies, potentially contributing to their stability and shelf life. Honey, known for its hygroscopic nature, could help maintain moisture levels and prevent the gummies from drying out due to its hygroscopic properties, while habbatussauda's antioxidant properties help preserve the gummies' quality by preventing oxidative degradation. These observations underscore the effectiveness of lower temperature storage in maintaining a stable water activity, which is critical for preserving the quality and safety of stored products.

Therefore, based on this finding, chilled storage would be the best for honey and Habbatussauda gummies for up to 3 months for optimal quality. Nevertheless, freezing temperature is preferable for the longer storage duration. However, room temperature storage is not advisable due to the substantial increase in moisture content over time.

B. Colour

Food product appearance has a significant impact on consumer preferences and acceptability of the product (Maina, 2018). This parameter plays a big role for most confectionery products in the market [8] since it affects the acceptability, taste thresholds, taste perception and expected pleasantness of the food. Through our observation over the six-month storage period, the L^* values, representing lightness, showed distinct trends depending on the storage conditions. Initially, the gummies stored at room temperature displayed a significant increase ($p < 0.05$) in L^* value from

42.20 ± 0.27 to 43.94 ± 0.84 during the first two months, followed by a significant ($p<0.05$) decline to 28.11 ± 0.59 by the sixth month. Conversely, the gummies stored in the chiller maintained relatively high L^* values, starting at 47.62 ± 0.57 and gradually decreasing to 42.04 ± 0.39 but the values fluctuated until the end of six months storage. Gummies stored in the freezer exhibited the most stable L^* values, with the range of 40.76 ± 0.96 to 48.34 ± 0.25 after six months storage.

Lightness (L^*)

Based on the data shown in Table 2.0, the best duration for maintaining the lightness of gummy candies is up to 2 months, regardless of storage temperature. After 2 months, the L^* values start to decrease, indicating a loss of lightness.

However, gummies stored at chilled, or freezer temperatures maintain their lightness better than those stored at room temperature. Storing gummies at lower temperatures helps slow down the rate of colour change and maintain the desired lightness for a longer period. The data clearly shows that storage temperature and duration are inversely related to the lightness of gummy candies. Higher temperatures and longer storage times lead to a decrease in L^* values, resulting in darker gummies. Lower temperatures, such as chilled or freezer conditions, help maintain the lightness of the gummies for a longer period. This is because lower temperatures slow down the rate of chemical reactions and microbial growth, which can contribute to colour changes and overall quality deterioration.

Table 2.0: Analysis of Gummy Develop using Honey and Habbatussauda with 6-Month Storage Durations

Mth (s)	Lightness (L^*)			Redness (a^*)			Yellowness (b^*)		
	Room	Chiller	Freezer	Room	Chiller	Freezer	Room	Chill	Freezer
1	42.16±0.21 ^{bB}	47.62±0.57 ^{aA}	48.34±0.25 ^{aA}	-0.32±0.01 ^{bE}	0.65±0.21 ^{aBC}	-.38±0.01 ^{bB}	6.18±0.05 ^{bAB}	8.8±0.09 ^{aA}	5.88±0.14 ^{cA}
2	43.94±0.84 ^{aA}	42.9±0.04 ^{bB}	42.81±0.17 ^{abB}	0.69±0.00 ^{aD}	0.53±0.02 ^{bC}	0.70±0.12 ^{aA}	5.25±0.38 ^{bBC}	4.35±0.11 ^{cB}	6.34±0.12 ^{aA}
3	30.88±0.14 ^{cC}	39.87±1.24 ^{bCD}	42.88±0.13 ^{aB}	1.56±0.17 ^{aA}	0.96±0.09 ^{bA}	0.74±0.08 ^{bA}	6.90±0.53 ^{cA}	8.49±0.41 ^{aA}	7.34±0.59 ^{bA}
4	31.01±2.3 ^{bC}	38.49±0.86 ^{aD}	39.70±1.22 ^{aC}	0.92±0.04 ^{aC}	0.84±0.06 ^{aAB}	0.83±0.08 ^{aA}	5.63±0.16 ^{bBC}	8.26±0.37 ^{aA}	7.65±0.15 ^{aA}
5	30.46±1.87 ^{bC}	41.59±0.56 ^{aBC}	41.21±0.11 ^{aC}	1.22±0.08 ^{aB}	0.77±0.07 ^{bABC}	0.69±0.08 ^{bA}	5.14±0.67 ^{bBC}	6.66±0.75 ^{aAB}	7.37±0.91 ^{aA}
6	28.11±0.59 ^{bC}	42.04±0.39 ^{aB}	40.76±0.96 ^{aC}	1.11±0.09 ^{aBC}	0.60±0.08 ^{bBC}	0.73±0.00 ^{bA}	4.90±0.69 ^{bC}	6.91±0.43 ^{aAB}	7.39±0.59 ^{aA}

*Means within each row (a-c) and column (A-C) with different superscripts are significantly different at $p<0.05$. Lower case letter indicates the effect of storage month and capital letter indicates the effect of storage temperature of gummy.

Redness (a^*)

The a^* values, which indicate the red/green colour component, showed a more varied trend across the different storage conditions. Gummies stored at room temperature demonstrated an increasing trend in a^* values, starting from -0.32 ± 0.04 and rising to 2.01 ± 1.11 by the sixth month, indicating a shift towards red. The gummies in the chiller exhibited minor fluctuations with initial a^* value of 0.53 ± 0.02 and ending at 0.96 ± 0.09, with minimal variation. For the gummies stored in the freezer, the a^* values remained relatively stable and low throughout, starting at -0.38 ± 0.01 and concluding at 0.83 ± 0.08, showing little change towards red or green. This phenomenon may be attributed to the degradation of certain colourants or the formation of new pigments due to chemical reactions at higher temperatures. In contrast, gummies stored in chilled and freezer conditions maintain more stable redness values, with minor fluctuations. This stability suggests that chilled and freezer temperatures help preserve the colour integrity of the gummies, likely by slowing down the reactions that lead to colour changes. Honey and habbatussauda (black seed) can contribute to the redness of gummy candies due to their natural pigments and compounds. Honey contains phenolic compounds and antioxidants that can enhance colour, while habbatussauda is rich in thymoquinone, which may impart a darker hue. The combination of these ingredients can lead to a more vibrant red colour in gummies. The best redness value for gummies is generally considered to be around 1.5 to 2.0 in the a^* scale, which indicates a desirable level of redness without compromising the overall quality and acceptability of the product. Maintaining this range is crucial for consumer appeal and product stability.

Yellowness (b^*)

Regarding the b^* values, which represent the yellow/blue colour component, the trends were relatively stable across the storage conditions. For room temperature storage, the b^* values ranged from 4.90 ± 0.69 to 6.18 ± 0.05. Gummies in the chiller generally maintained higher b^* values, with an initial value of 8.80 ± 0.09, whereas the lowest value was observed at 4.35 ± 0.11 after six months. Gummies stored in chilled conditions have more stable yellowness values throughout the storage period, peaking in the first month and gradually decreasing thereafter. Meanwhile, gummies stored in the freezer displayed minor changes, with b^* values at 7.34 ± 0.59 indicating a consistent yellowness throughout the storage period. A study done before confirmed and Kean (2014) revealed that confectionery products made without stabilisers and coloured with anthocyanins resulted in decreased colour storage stability as the processing temperatures increased. Furthermore, the Maillard process and high-temperature caramelization are also one of the relevant contributing factors [28]. The freezer condition also shows relatively stable yellowness, with values consistently higher than those at room temperature. This suggests that lower temperatures, particularly chilling and freezing, help preserve the yellowness of gummies by slowing down the degradation of colourants and preventing chemical reactions that could lead to colour loss.

Honey and habbatussauda (black seed) can enhance the yellowness of gummy candies due to their natural compounds. Honey contains various sugars and phenolic compounds that can impart a golden hue to the gummies, while habbatussauda is rich in carotenoids, which are known

for their yellow and orange pigments. The incorporation of these ingredients can lead to a more vibrant yellow colour in the final product. The best yellowness value for gummies is typically around 8.0 to 9.0 on the b* scale, indicating a desirable level of yellowness that enhances visual appeal without compromising overall quality. Maintaining this range is crucial for consumer acceptance and product stability. Based on the observed colour stability, storing gummies in the freezer is recommended for maintaining the best colour quality over time. The freezer conditions minimised changes in lightness, redness, and yellowness, preserving the gummies' original appearance more effectively than room temperature or chiller storage. The optimal duration for maintaining the best yellowness quality in gummy candies appears to be within the first two months of storage, especially in chilled or freezer conditions. During this period, yellowness values are at their highest, particularly in the chilled condition, where the values remain above 8.0. After the second month, yellowness values tend to decline, particularly at room temperature, indicating that prolonged exposure to higher temperatures negatively affects colour quality. Therefore, to ensure the best appearance and sensory attributes, it is advisable to consume or evaluate gummy candies within the first two months, particularly when stored in cooler environments.

C. Texture Profile Analysis (TPA)

When evaluating the quality of natural and formulated foods, the texture is examined. Thus, instrumental Texture Profile Analysis (TPA) is employed as a one-cycle imitative test whereby the food sample is compressed between two parallel surfaces twice or more [22]. As for the gelled confections, the texture descriptors of hardness, gumminess, and chewiness are very relevant [2] [5].

Hardness can be defined as the strength of a material's gel structure under compression [26]. It stipulated the peak force (force required to achieve a given deformation) of the area during the first compression cycle, which is represented by the first bite [27]. Gumminess refers to the sticky and cohesive texture of a food product, describing how well it holds together when bitten. In gummy candies, gumminess indicates how much energy is needed to break the candy apart after chewing. On the other hand, chewiness is the measure of how much effort is required to chew a food product until it is ready to swallow. It reflects the time and energy needed to break down the food in the mouth. In gummies, chewiness is influenced by factors like moisture content and the type of gelling agents used, contributing to a satisfying eating experience.

Table 3.0a: The texture profile analysis (TPA) of Gummy Develop using Honey and Habbatussauda with 6-Months Storage Durations at Room Temperature

Month	Hardness	Springiness	Cohesiveness	Gumminess	Chewiness	Resilience
1 st	1997.32±52.57 ^e	0.97±0.01 ^{ab}	0.81±0.01 ^b	1755.32±96.36 ^e	1665.34±37.12 ^d	0.52±0.00 ^a
2 nd	4075.82±51.42 ^c	0.97±0.04 ^{ab}	0.89±0.02 ^a	4171.37±76.83 ^c	4230.86±7.30 ^b	0.53±0.01 ^a
3 rd	5270.40±70.17 ^{ab}	1.00±0.00 ^a	0.87±0.00 ^{ab}	4586.54±41.80 ^b	4316.32±47.41 ^b	0.48±0.00 ^{bc}
4 th	6032.94±13.48 ^a	0.94±0.00 ^b	0.87±0.00 ^{ab}	5196.22±26.60 ^a	5019.70±55.64 ^a	0.48±0.03 ^c
5 th	5188.97±63.55 ^{ab}	0.96±0.00 ^{ab}	0.87±0.02 ^{ab}	4507.13±39.27 ^b	4317.51±24.49 ^b	0.48±0.00 ^c
6 th	3854.24±48.92 ^d	0.96±0.00 ^{ab}	0.85±0.00 ^b	3257.04±5.09 ^d	3097.54±2.38 ^c	0.49±0.00 ^b

*Values with ^{a-c} letters indicate significantly different (p<0.05) as measured by ANOVA.

Room Temperature

Table 3.0a, gummies stored at room temperature showed increase in hardness however exhibited stable hardness till the fifth month, with no significant increase. However, the hardness progressively decreased thereafter. This trend suggests that the gummies initially maintained their texture but became softer over time. The gradual reduction in hardness indicates that room temperature storage is not optimal for preserving the desired firm texture of gummies for an extended duration. Springiness remained relatively stable initially but decreased slightly from 1.00 ± 0.0 to 0.94 ± 0.00. Cohesiveness showed minimal variation, while gumminess and chewiness increased initially but then decreased towards the end of the storage period. Resilience slightly decreased from 0.53 ± 0.01 to 0.49 ± 0.00, suggesting a decline in the gummy's ability to recover its shape after deformation whereby overall textural quality deteriorated by the sixth month. Research indicates that higher temperatures can lead to increased moisture loss and sugar crystallisation, both of which negatively impact the texture of gummy

candies [5][3]. Specifically, moisture loss can cause gummies to become softer, as water content is crucial for maintaining their structure and firmness. Conversely, sugar crystallisation can lead to a firmer texture; however, this process may also result in uneven texture and undesirable changes in mouthfeel. Additionally, to maintain the ideal firmness and quality of gummies, it is advisable to store them in cooler conditions, which help minimise moisture loss and prevent undesirable crystallisation.

Chilled Temperature

Table 3.0b shows gummies stored under chilled conditions exhibited a different trend. Hardness significantly (p<0.05) increased from 7025.95 ± 28.67 g to 9435.46 ± 94.62 g, which is a higher rate compared to room temperature storage, before dropping to 6,093.79 g in the sixth month storage (Table 3.0b). The increments in hardness may be attributed to the stabilisation of moisture content at lower temperatures, which helps maintain the structural integrity of the gummies ([15] [16]. Springiness showed a notable peak in the second month

Table 3.0b: The texture profile analysis (TPA) of Gummy Develop using Honey and Habbatussauda with 6-Months Storage Durations at Chilled Temperature

Month	Hardness	Springiness	Cohesiveness	Gumminess	Chewiness	Resilience
2 nd	7025.95±28.67 ^c	1.38±0.07 ^a	0.89±0.00 ^a	6252.98±97.58 ^c	6560.02±81.85 ^b	0.57±0.01 ^a
3 rd	7627.32±19.79 ^b	0.99±0.00 ^b	0.88±0.00 ^a	6737.24±22.66 ^b	6708.50±17.17 ^b	0.52±0.00 ^b
4 th	7875.57±11.59 ^b	0.99±0.00 ^b	0.87±0.00 ^a	6782.20±24.56 ^b	6769.37±42.72 ^b	0.50±0.01 ^b
5 th	9435.46±94.62 ^a	0.98±0.02 ^b	0.89±0.02 ^a	7438.93±32.08 ^a	7762.98±77.62 ^a	0.57±0.03 ^a
6 th	6093.79±64.63 ^d	1.00±0.01 ^b	0.88±0.00 ^a	5208.78±20.79 ^d	4991.15±93.33 ^c	0.55±0.00 ^a

Values with ^{a-c} letters indicate significantly different (p<0.05) as measured by ANOVA.

Table 3.0c: The texture profile analysis (TPA) of Gummy Develop using Honey and Habbatussauda with 6-Months Storage Durations at Freezing Temperature

Month	Hardness	Springiness	Cohesiveness	Gumminess	Chewiness	Resilience
2 nd	6889.32±54.51 ^b	1.24±0.02 ^a	0.89±0.02 ^a	4730.41±86.36 ^d	4617.96±58.48 ^c	0.54±0.01 ^a
3 rd	6794.34±78.81 ^b	0.96±0.00 ^b	0.89±0.01 ^a	6097.80±98.48 ^b	5703.15±22.02 ^b	0.52±0.00 ^{ab}
4 th	6884.43±53.03 ^b	1.01±0.00 ^b	0.88±0.00 ^a	6044.72±2.78 ^b	5550.22±1.08 ^b	0.52±0.00 ^{ab}
5 th	7672.78±48.62 ^a	0.98±0.03 ^b	0.86±0.01 ^a	6595.70±1.05 ^a	6435.13±81.41 ^a	0.51±0.00 ^b
6 th	5860.07±6.59 ^c	1.00±0.00 ^b	0.87±0.00 ^a	5097.29±1.83 ^c	4746.36±20.21 ^c	0.53±0.01 ^a

Values with ^{abc} letters indicate significantly different (p<0.05) as measured by ANOVA.

but decreased thereafter, which could indicate that while the gummies were initially elastic, prolonged storage led to some textural degradation. Cohesiveness remained stable, suggesting that the formulation retained its ability to hold together effectively. The gumminess and chewiness increased significantly, particularly in the fifth month, indicating that the gummies were not only firmer but also maintained a desirable chewy texture, likely due to the optimal moisture retention at chilled temperatures[6] . Resilience values were also consistent, indicating that the gummies could still recover well after deformation.

Freezer

Gummies stored in the freezer showed a relatively stable trend in texture attributes (Table 3.0c). Hardness values possess no significant difference between 6,889.32 g and 7,672.78 g, which suggests that freezing effectively preserves the texture and prevents moisture loss [3]. Springiness showed an initial value of 1.24 but later stabilised around 0.90 to 1.00. The normal range for springiness in Texture Profile Analysis (TPA) of gummy candies typically falls between 0.90 and 1.50. This range indicates the degree to which the gummy returns to its original shape after deformation, reflecting its elasticity and chewiness (Khouryieh *et al.*, 2005). Additionally, the specific formulation and processing conditions, such as the concentration of gelling agents like gelatine, can significantly influence the springiness of the final product [14]. Therefore, maintaining springiness within this range is crucial for achieving the desired texture and mouthfeel in gummy candies. Cohesiveness remained steady. Gumminess and chewiness increased initially but showed a slower rate of change compared to room temperature and chilled storage. Resilience remained relatively constant and high throughout the storage period.

Springiness remained relatively high, indicating that the gummies retained their elasticity, while cohesiveness was consistent throughout the storage period. Gumminess and chewiness were highest in the fifth month, indicating that the texture was well-preserved, likely due to the low temperatures preventing the crystallisation of sugars and maintaining moisture levels [5]. Resilience values were stable, suggesting that the gummies maintained their structural integrity and ability to recover after deformation.

Based on the observed trends, chilled storage appears to offer the best balance for maintaining gummy texture quality over time. The gummies stored in the chiller exhibited increased hardness but also maintained higher springiness and chewiness compared to those stored at room temperature. The slight decline in resilience was less pronounced than in the room temperature samples. Chilled storage conditions help in preserving the texture attributes by slowing down the rate of moisture loss and texture changes compared to room temperature. The increase in hardness and changes in springiness and chewiness can be attributed to moisture loss and polymer crystallisation. At room temperature, higher temperatures accelerate the evaporation of moisture, leading to increased hardness and reduced springiness. Chilled and freezer conditions slow down this process, but the gummies still become harder over time due to the gradual crystallisation of sugars and gelling agents. Freezing slows these changes significantly, resulting in a slower rate of hardness increase and better preservation of texture attributes. The relatively stable resilience in the freezer suggests minimal structural breakdown of the gummy matrix [30] [36].

Honey and Habbatussauda may contribute to the springiness of gummy formulations due to their unique properties. Honey is a natural humectant, which means it could attract and retain moisture. This moisture retention can enhance the elasticity

and overall texture of gummies, allowing them to recover better after deformation, which is a key characteristic of springiness [3]. The presence of sugars and other components in honey can also influence the gel structure, potentially leading to improved mouthfeel and chewiness (Garrido *et al.*, 2014). Habbatussauda, while primarily known for its health benefits due to its bioactive compounds, may also play a role in the texture of gummies. Its oil content can contribute to the overall moisture balance in the formulation, although its effect on springiness may be less pronounced compared to honey. The combination of these ingredients can create a synergistic effect, enhancing the textural attributes of the gummies, including springiness [15] [16]. In conclusion, both honey and Habbatussauda can positively influence the springiness of gummy formulations, with honey being the more significant contributor due to its humectant properties and ability to retain moisture. This makes them valuable ingredients in the development of gummies that are not only flavourful but also possess desirable textural characteristics.

D. Thermal Stability (Tg) Testing

The Table 4.0a showed the thermal stability of gummy candies formulated with honey and *Habbatussauda* was evaluated over a 6-month storage period at room, chilled, and freezing temperatures using a differential scanning calorimeter (DSC). At room temperature, the thermal stability of the gummy candies significantly declined over time, as indicated by a decrease in the onset temperature from 120.52°C in the second month to 109.19°C by the sixth month, alongside a reduction in the enthalpy of gelatinisation (ΔH_{gel}) from 11.781 J/g to 5.605 J/g.

Table 4.0a: Thermal Properties of Gummy Candies Developed with Honey and Habbatussauda: A 6-Month Storage Study at Room Temperature Using Differential Scanning Calorimeter

Mth	Onset Temperature (To)	Peak Temperature (Tp)	End Temperature (Te)	Enthalpy of gelatinisation ΔH_{gel} (J/g)
2 nd	120.52	121.37	123.37	11.781
3 rd	113.55	115.20	116.24	6.401
4 th	114.90	116.67	117.33	5.931
5 th	109.88	111.17	111.67	5.664
6 th	109.19	110.20	111.20	5.605

This suggests that prolonged storage at room temperature results in increased molecular mobility and degradation of the gel matrix, negatively affecting the gummies' structural integrity, as also observed in similar studies where increased temperatures led to reduced gel strength and stability in gelatine-based products [21]. In contrast, gummies stored at chilled temperatures exhibited variability in thermal properties, with the onset temperature peaking at 142.88°C in the third month and then gradually decreasing (Table 4.0b). Despite these fluctuations, the ΔH_{gel} remained relatively stable, ranging from 7.989 J/g to 8.974 J/g. This stability suggests that chilled storage helps maintain the gummies' structural integrity better than room temperature storage, although minor changes may still occur due to moisture loss

or crystallisation [37]. Similar findings have been reported in previous research, where lower storage temperatures helped preserve the physical and thermal properties of edible gels and confections by minimising moisture migration and molecular mobility [25][32].

Table 4.0b: Thermal Properties of Gummy Candies Developed with Honey and Habbatussauda: A 6-Month Storage Study at Chilled Temperature Using Differential Scanning Calorimeter

Mth	Onset temperature (To)	Peak Temperature (Tp)	End Temperature (Te)	Enthalpy of gelatinisation ΔH_{gel} (J/g)
2 nd	109.38	110.53	111.37	8.974
3 rd	142.88	144.37	146.26	7.989
4 th	116.13	116.50	116.83	8.149
5 th	113.58	114.50	115.73	8.413
6 th	112.84	113.37	113.87	8.726

Notably, freezing temperatures provided the most stable thermal properties, with consistent onset and peak temperatures throughout the storage period as shown in Table 4.0c. The ΔH_{gel} was the highest, reaching 16.247 J/g in the third month and 19.600 J/g in the sixth month. This implies that freezing not only maintains but potentially enhances the thermal stability of the gummies by reducing molecular mobility and preserving the gel structure effectively. Such enhancements in thermal stability under freezing conditions have been corroborated by studies indicating that low temperatures can inhibit enzymatic and non-enzymatic reactions that contribute to the degradation of gel structures in food products ([25][34][35]). Overall, the study concludes that freezing is the most effective storage method for maintaining the thermal properties of gummy candies, followed by chilled storage, with room temperature being the least effective.

Table 4.0c: Thermal Properties of Gummy Candies Developed with Honey and Habbatussauda: A 6-Month Storage Study at Freezing Temperature Using Differential Scanning Calorimeter

Mth	Onset temperature (To)	Peak Temperature (Tp)	End Temperature (Te)	Enthalpy of gelatinisation ΔH_{gel} (J/g)
2 nd	127.81	128.53	130.00	11.553
3 rd	117.18	118.50	122.45	16.247
4 th	126.53	127.37	128.03	12.065
5 th	110.83	113.20	115.37	11.402
6 th	108.60	111.50	113.18	19.600

IV. CONCLUSION

This study explored the impact of different storage conditions on the moisture content, water activity, colour, and texture of gummies made with honey and habbatussauda

over six months. Moisture content increased over time across all storage conditions, particularly in the final month, with the highest increase observed at room temperature. Despite the rise in moisture content, water activity remained relatively stable, suggesting that the proportion of free water did not significantly change, likely due to the binding properties of the ingredients and the restrictive nature of lower temperatures.

Texturally, gummies stored at room temperature showed increased hardness and changes in springiness, gumminess, and chewiness over time, leading to a decline in overall quality by the sixth month. The findings suggest that lower temperature storage is optimal for maintaining the colour, moisture stability, and texture of gummies, supporting longer shelf life and improved sensory quality. Colour stability was another critical factor, with lightness (L^*), redness (a^*), and yellowness (b^*) values showing distinct trends depending on storage conditions. Gummies stored in the freezer maintained better colour stability than those stored at room temperature or in the chiller.

In conclusion, the study found that lower storage temperatures, particularly freezing, are more effective in preserving the moisture content, colour, and texture of gummies. The inclusion of honey and habbatussauda also contributed to maintaining the gummies' stability, making these ingredients valuable for extending shelf life and improving product quality.

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