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Development of Antioxidant-Rich Gummies by Utilizing Pomegranate Juice and Water Chestnut Extract to Boost Immune System

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ABSTRACT

Consumption at high levels is attributed to health hazards. Pomegranate juice and water chestnut extract possess antioxidant and immune-enhancing properties, making them a healthy gummy alternative to conventional gummies. The aim of this study was the formulation of gummies with antioxidant-rich pomegranate juice and water chestnut extract to enhance their nutritional, sensory, functional properties, and to boost immune system. Pomegranate to water chestnut ratios 50:50, 70:30, and 60:40 along with the control were prepared in three formulations. Proximate, phytochemical, textural, and microbial characteristics were analyzed using standard methods. However, organoleptic properties and shelf-life of the product was also determined. A 9-point hedonic scale was used to evaluate the sensory parameters of the developed product. Proximate analysis showed Sample B (70:30) had the lowest percentage for moisture 18.5%, the highest percentage for protein, 1.3%, and the percentage for carbohydrates, 79.2% leading to a firmer texture. Phytochemical analysis showed Sample B as having the highest percentage total phenolic content with 5.8 mg GAE/g and flavonoid content of 4.1 mg QE/g which led to strong antioxidant activity with 70% inhibition and the lowest IC₅₀ value at 6.2 mg/mL. Texture evaluation showed that Sample B had the highest rating for hardness at 3.5 N, chewiness at 0.8, and cohesiveness at 0.7 of textures, which meant better textural integrity. Microbiological assessment showed that Sample B was the lowest level of microbial activity at 1500 CFU/g after 8 weeks of storage and thus attributed to longer shelf life. The sensory analysis favored Sample B having the highest overall acceptability score of 9, attributed by its good balance of flavors, texture, and mouthfeel. These results establish a suitable sensory appeal, good antioxidant properties, and boosting of immune functionality through the 70:30 pomegranate-to-water chestnut formulation. The developed product can be suggested as a promising functional food product. Its future research lines may include natural sweeteners and clinical trials evaluating long-term health impacts.

INTRODUCTION

Confectionery products are usually consumed by children and adults (James, 2013). In Pakistan, jellies and gummies are widely consumed by children, with a huge proportion of children aged 6-8 years consuming them more than once a week. While there is no specific national statistics, large percentages of children of this age, especially urban residents, consume jellies and gummies at least three times a week, mainly because of the availability of these products and their affordable cost, coupled with their sweetness and bright colors. Such high consumption rates of these products raise several health concerns, especially about the kind of health risks they present with their high sugar content and artificial additives. However, jellies and gummies achieve mass popularity among all users aged less than 17 years because these products are organic and chewy in nature (Teixeira-Lemos *et al.*, 2021). The structure of these products is jelly-like; the main constituents are fruits of at least 45 g/100 g and sugars in the sucrose syrup and/or glucose, in concentrations of about 55 g/100 g, along with gelling agents, acids, flavors, and food colorants (Lee & Kim, 2019). Their low nutritional values have also been challenged and industries

are being compelled more and more to decrease sugar in these products to respond to consumer demand for healthier formulations.

Depending on global trends, excessive consumption of sugar-based jellies and gummies has been linked to the rising tides of obesity, tooth decay, and hyperglycemia (Khawaja *et al.*, 2019). To address this, fruit juices such as pomegranate and water chestnut are included in the production of gummies to better replace them. Fruit juices contain high concentrations of vitamins, antioxidants, and bioactive compounds such as polyphenols and flavonoids that enhance the strength of the immune system and health as a whole (Cano-Lamadrid *et al.*, 2020; Miles & Calder, 2021). Other alternatives would be replacing the use of refined sugars with natural sweeteners like honey. Honey has a low glycemic index and high nutrient profile. It is, therefore, a good natural substitute to enhance flavor and add antibacterial properties with antioxidant effects, thus making this gummy product appealing to health-conscious consumers with lowered sugar content (Mutlu *et al.*, 2018).

The use of natural juices or purees of oranges, strawberries, and other fruits or even fruit by-products

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has been considered for the manufacturing of jellies (Cano-Lamadrid *et al.*, 2018). These can not only improve the organoleptic properties (color, flavor, and texture) of gummies and jellies but also produce healthier formulations with antioxidant properties (de Moura *et al.*, 2019). Recent works have proved that the addition of anthocyanin extracts to gelatin and pectin gels could not only be an alternative to synthetic colorants but may also have a positive health effect for those who consumed the products in moderate quantities (Xie *et al.*, 2018). Considering that jellies or gummies have to be produced with improved nutritional properties but maintaining their classical textural properties, our research group developed various alternative formulations (Guiné *et al.*, 2018). In the preceding study, Guiné *et al.* (2018) looked at several different blends with fruits and herbs with the aim of introducing natural flavor apart from these ingredients' natural color contribution by natural colorants (Guiné *et al.*, 2018). Berry fruits used for the preparations in the formulated products were strawberry, raspberry, and blueberry, which are known to be rich in anthocyanins and other phenolics with antioxidant activities. Besides, anise and mint that were applied above also in these formulations are natural flavor enhancers with bioactive active agents (Dzhanfezova *et al.*, 2020).

Pomegranate is a fruit that has been found to have health benefits primarily as it is rich in antioxidants, polyphenols, and other bioactive compounds. Among these are punicalagins and ellagic acid, major antioxidants, which neutralize free radicals; free radicals dissipate and lessen oxidative stress and inflammation that occurs within the body. Ellagic acid is an antioxidant also famous for inhibiting cancerous cell growth and positively affecting cardiovascular health. It contains much other flavonoids, such as anthocyanins and catechins, with more anti-inflammatory and immune-enhancing properties (Pirzadeh *et al.*, 2021; Yang *et al.*, 2023). Pomegranate is also a rich source of vitamin C: the very crucial nutrient that stimulates production of white blood cells and enhances general immunity as well. These combined compounds make pomegranate a powerful ally in the boosting of immune defense mechanisms, reduction of chronic disease risk, and promotion of heart and skin health (Baradaran Rahimi *et al.*, 2020). Consequently, the nutty flavor of water chestnut (*Eleocharis dulcis*) is attributed to its high nutrient content primarily antioxidants and minerals that make the food promote health. Ferulic acid is one of the main bioactive compounds in the water chestnuts, known as a powerful antioxidant: Ferulic acid is a power antioxidant very effective in neutralizing free radicals, the results of which are the reduction of oxidative stress in the body. They are rich in dietary fiber protecting the digestive system, as any healthy gut microbiome means a good and strong immune system (Zhang *et al.*, 2022). Lastly, water chestnuts are replete with minerals such as potassium, known for regulation in blood pressure and maintenance in cardiovascular health. Water chestnuts are healthy additions to any diet,

combining the antioxidant, fiber, and essential mineral benefits to ensure proper nutrition for overall well-being and immune health (Rajput & Singh, 2023).

Therefore, this study aimed to develop antioxidant rich gummies by utilizing pomegranate juice and water chestnut extract to boost immune system.

These formulations sought to upgrade the nutritional and functional properties of traditional gummies by utilizing natural fruit juices and bioactive compounds. The effects of different ratios between pomegranate and water chestnut juice on the phytochemical content, antioxidant activity, texture, microbial stability, and sensory properties of the gummies are analyzed. Furthermore, the study also addresses the feasibility of employing such preparations in improving the immune state through natural ingredients carrying polyphenols, flavonoids, among other biologically active compounds. This paper addresses the increased consumer demand for healthier confectionery by substituting sugar and synthetic additives with natural fruit juices and sweeteners. While traditional gummies tend to be high in sugar and additives, with negative health effects such as obesity and hyperglycemia, limited research exists on functional gummies using immune-boosting extracts from natural ingredients. This gap is filled by research in the introduction of pomegranate and water chestnut extracts as alternative formulations to the traditional ones. It supports the development of confectionery products that not only appeal to the consumer's taste but also provide significant health benefits.

MATERIALS AND METHODS

Materials and Juice Extraction

Fresh pomegranates (*Punica granatum*) were purchased from a local market and cleaned, then pressed through a commercial juicer. The juice was filtered through cheesecloth to remove any seeds and pulp, and pure pomegranate juice was obtained. The same operations were applied to fresh water chestnuts (*Eleocharis dulcis*), peeled, boiled, juiced and filtered to obtain clear water chestnut extract. For the base gel, gelatin was used. Sugar, citric acid, glucose syrup, and water were mixed and cooked at 80-90°C. Sodium benzoate was added to the gummies as a preservative when the gummies were formulated to have a longer shelf life. A control version of the gummy was prepared from a standard recipe (Puch *et al.*, 2019).

Gummy Preparation

Three different gummy formulations were developed that had different proportions of pomegranate juice and water chestnut extract. The samples prepared consisted of Sample A (50 ml pomegranate juice + 50 ml water chestnut extract), Sample B (70 ml pomegranate juice + 30 ml water chestnut extract), and Sample C (60 ml pomegranate juice + 40 ml water chestnut extract). The juice blends were combined with the gummy base ingredients: gelatin, sugar, citric acid, and glucose syrup,

in a pan. The mixture was then heated to 90°C with continuous stirring to ensure that the base ingredients melt uniformly. After heating, the mixture was poured into molds and allowed to set at room temperature for 12 hours. A control gummy formulation was similarly prepared but devoid of any fruit extracts (Pekdogan Goztok *et al.*, 2024).

Proximate Analysis

Proximate analysis was conducted to establish the nutritional profile of the gummies. Moisture content was measured by oven drying at 105°C until constant weight was attained. Ash content was conducted through the incineration of gummy samples by a muffle furnace at 550°C. Crude proteins content was carried out by the Kjeldahl method, and fat content was determined by extracting the fat via Soxhlet extraction method using petroleum ether. The carbohydrate was determined by the difference as 100% minus the moisture, ash, protein, and fat percent (AOAC, 2019; Teixeira-Lemos *et al.*, 2021).

Texture Analysis

The mechanical properties of the gummies were determined by Texture Profile Analysis (TPA). Their hardness was determined by the force required to compress the gummy samples, while chewiness was calculated as the product of gumminess and elasticity, with cohesiveness found as the ratio of the second compression to the first and reflects the internal structure. The applied force will depend on the instrument settings- the probe speed and the compression depth- for around 2.5-3.5 N values representing the forces applied to compress gummy samples (Teixeira-Lemos *et al.*, 2021).

Microbial Analysis

The microbial load was determined through total plate counts, yeast, and mold counts. Incubated samples were the gummies placed on the nutrient agar plates at 37°C for 24-48 hours to determine CFU per gram. Under varied time points at weeks 1, 2, 4, and 8; it followed the changes over time in refrigerated (4°C) and ambient temperatures (Rubio-Arreaz *et al.*, 2015; Teixeira-Lemos *et al.*, 2021).

Sensory Evaluation

A sensory evaluation was conducted using a 9-point hedonic scale for appearance, color, texture, mouthfeel, flavor, taste, and overall acceptability. Thirty panelists consisting of both trained as well as untrained were taken into account. Randomly coded samples of each gummy formulation (50:50, 70:30, 60:40) as well as the control were presented to the panelists who rated each sample on a hedonic scale from 1 (dislike extremely) to 9 (like extremely). The sensory acceptability of each formulation was assessed by averaging the scores (Mahat *et al.*, 2020; Teixeira-Lemos *et al.*, 2021).

Phytochemical Analysis

Phytochemicals of gummy formulations were characterized, while bioactive compounds contributing to functional properties were quantified. Total Phenolic Content (TPC) was evaluated using the Folin-Ciocalteu method and expressed as milligrams of gallic acid equivalents per gram (mg GAE/g) of gummy, indicating antioxidant potential of phenolics. The total flavonoid content was determined using the aluminum chloride colorimetric method, and the results obtained are expressed as mg QE/g of gummy. The flavonoids present in this formulation play the role of antioxidants and anti-inflammatory agents that lend credence to the supposed health implications of this formulation (Ali *et al.*, 2021). The antioxidant activity of the gummies was determined by utilizing the DPPH radical scavenging assay. Data were expressed as a percentage of free radical inhibition and as the half-maximal inhibitory concentration (IC₅₀): the concentration of gummy required to inhibit 50% of the DPPH radicals (Gonçalves *et al.*, 2015; Teixeira-Lemos *et al.*, 2021).

Data Analysis

All the data was subjected to statistical analysis using ANOVA to determine significant differences in samples for each parameter studied. All experiments were conducted in triplicates in order to ensure accuracy and reliability of the data obtained. A significance level of $p < 0.05$ was used in determining the statistical significance between the formulations. This study design seamlessly integrates proximate analysis, texture profiling, microbial stability, sensory evaluation, and phytochemical testing based on the existing scientific methods in developing functional foods. The employment of natural fruit extracts of pomegranate and water chestnut strengthened the nutritional and functional properties of the gummy candies and supports the prevailing trends in developing health-promoting confectioneries.

RESULTS AND DISCUSSION

Results

The results section comprises proximate analysis, texture analysis, microbial analysis, shelf-life determination, organoleptic properties and product sensory evaluation. A 9-point hedonic scale was used to evaluate the sensory parameters of the developed product. The phytochemical analysis carried out on the antioxidant-rich gummies indicated that Sample B, with the formulation 70:30 Pomegranate: water chestnut Juice contained the highest bioactive content. Sample B showed the highest total phenolic content at 5.8 mg GAE/g and flavonoid content at 4.1 mg QE/g, both necessary to its high antioxidant capacity. It achieves the maximum antioxidant activity (70% inhibition), as well as the lowest IC₅₀ value; 6.2 mg/mL. Therefore, showed the capability to neutralize

free radicals is strongest at a lower concentration. The findings have led to an inference that Sample B is the most powerful immune boosting formula that utilizes the bounty of polyphenols and flavonoids present in pomegranate juice. Sample A (50:50) and Sample C

(60:40) also exhibit excellent antioxidant activity, but the higher concentration of pomegranate in Sample B offers the perfect balance of sensory appeal and functional health benefits-a more effective formulation to support immune health, as shown in Table 1.

Table 1: Phytochemical Analysis

Parameter	Control	Sample A (50:50)	Sample B (70:30)	Sample C (60:40)
Total Phenolic Content (mg GAE/g)	2.0	4.5	5.8	5.0
Total Flavonoid Content (mg QE/g)	1.2	3.0	4.1	3.5
Antioxidant Activity (% inhibition)	25	55	70	65
IC50 (mg/mL)	20.0	8.5	6.2	7.0

Table 2: Proximate Analysis

Parameter	Control	Sample A (50:50)	Sample B (70:30)	Sample C (60:40)
Moisture (%)	20.5	19.8	18.5	19.0
Ash (%)	0.2	0.6	0.7	0.6
Protein (%)	0.8	1.2	1.3	1.2
Fat (%)	0.1	0.2	0.3	0.2
Carbohydrates (%)	78.4	78.2	79.2	79.0

Table 2 presents the proximate analysis of the developed gummies. Proximate analysis of the gummy formulations is essential as there are clear differences between the groups in terms of moisture, ash, protein, fat, and carbohydrate content. Sample B has the lowest moisture content at 18.5%, thus attributing a firmer textural property than the other formulations. The sample also contains the highest ash content standing at 0.7%, thus attributing more minerals, and this is

apparently attributed to the high concentration of pomegranate juice. The protein content is highest in Sample B, meaning the enhanced nutritional profile relative to the control and other formulations. Sample B also has the highest amount of fat content (0.3%) and carbohydrate content (79.2%), respectively. Conversely, the control sample showed the lowest ash, protein, and fat values, hence meaning that there was no existence of the functional ingredients.

Table 3: Texture Analysis

Parameter	Control	Sample A (50:50)	Sample B (70:30)	Sample C (60:40)
Hardness (N)	2.5	3.2	3.5	3.3
Chewiness	0.5	0.7	0.8	0.75
Cohesiveness	0.6	0.65	0.7	0.68

The texture profile analysis of the gummy formulations in Table 3 displays varied differences in hardness, chewiness, and cohesiveness between samples. Sample B, with a 70:30 ratio of pomegranate and water chestnut, showed to have the highest hardness at 3.5 N, firm and structured. This might be attributed to its higher amount of concentration of pomegranate juice that can form a gel matrix. Sample B has the highest value for chewiness at 0.8, meaning that the

product is more firm and would require a longer chewing time, hence something desirable in gummies. It also obtains the highest cohesiveness score at 0.7, representing its better structural integrity since it keeps together well upon mastication. Conversely, Sample A (50:50) and Sample C (60:40) gave slightly lower values for all the texture parameters while control samples gave the lowest values, which means a softer, less cohesive texture.

Table 4: Microbial Analysis

Days (Weeks)	Control	Sample A (50:50)	Sample B (70:30)	Sample C (60:40)
1 (Week 1)	<100 CFU/g	<100 CFU/g	<100 CFU/g	<100 CFU/g
14 (Week 2)	500 CFU/g	200 CFU/g	150 CFU/g	180 CFU/g
28 (Week 4)	1500 CFU/g	800 CFU/g	500 CFU/g	700 CFU/g
56 (Week 8)	5000 CFU/g	3000 CFU/g	1500 CFU/g	2500 CFU/g

Table 4 indicates the microbial analysis for all samples over eight weeks. In the first week for all samples a microbial count of below 100 CFU/g was examined. However, by the second week onward, microbial growth tends to differ. The count reaches its peak for the control sample at 500 CFU/g, whereas Sample B (70:30) showed the least count of microbes at 150 CFU/g, thus suggesting better preservation. As the storage period advances to four weeks, microbial counts increase more. The control reaches 1500 CFU/g, while Sample B again had the lowest microbial load at 500 CFU/g, indicating that the higher

concentration of pomegranate juice in Sample B may provide better antimicrobial properties. At week eight, the peak in microbial counts was reached and the control sample exhibited 5000 CFU/g, while Sample B still had a highly significant lower microbial count of 1500 CFU/g followed by Sample C (2500 CFU/g) and Sample A (3000 CFU/g). The analysis indicated that Sample B had the best microbial stability, which could be due to the natural antimicrobial properties of pomegranate juice containing bioactive compounds such as polyphenols inhibiting the growth of microbes.

Table 5: Sensory Evaluation

Parameter	Control	Sample A (50:50)	Sample B (70:30)	Sample C (60:40)
Appearance	6	7	8	7
Color	6	7	8	8
Texture	6	6	8	7
Mouthfeel	6	7	9	6
Flavor	5	7	9	8
Taste	5	6	8	8
Overall Acceptability	5	7	9	8

Evaluation by the senses of the formulations of the gummies concerning the appearance, color, texture, mouthfeel, flavor, and taste as well as the overall acceptability indicated that Sample B was preferred with a 70:30 ratio for pomegranate to water chestnut, and its overall acceptability was reported to be 9, indicating the consumer preferred most balanced sensory attributes. It scored well in appearance, color, and texture at 8. Notably, Sample B excels in mouthfeel, 9 and flavor, 9 points, where higher concentration of pomegranate may give a deep, fruity flavor and have a satisfying chew. The taste score of 8 further reflects its perfectly well-rounded sweetness and tartness contributed by pomegranate juice.

The 60:40 Sample C also showed good results in terms of sensory, especially on flavor and taste at 8 each, but loses a bit in overall acceptability as compared to Sample B due to lower ratings for mouthfeel at 6 and texture at 7. However, Sample A (50:50) scores were generally in the middle range for all parameters and had an overall acceptability of 7, thus indicating that it was still a good option but not as attractive as Sample B. The control sample scored the lowest with an overall acceptability of 5, which justifies the point of incorporating pomegranate and water chestnut to enhance the sensory appeal of the final product. Considering overall acceptability, Sample B was considered the best formulation to satisfy consumers' desire.

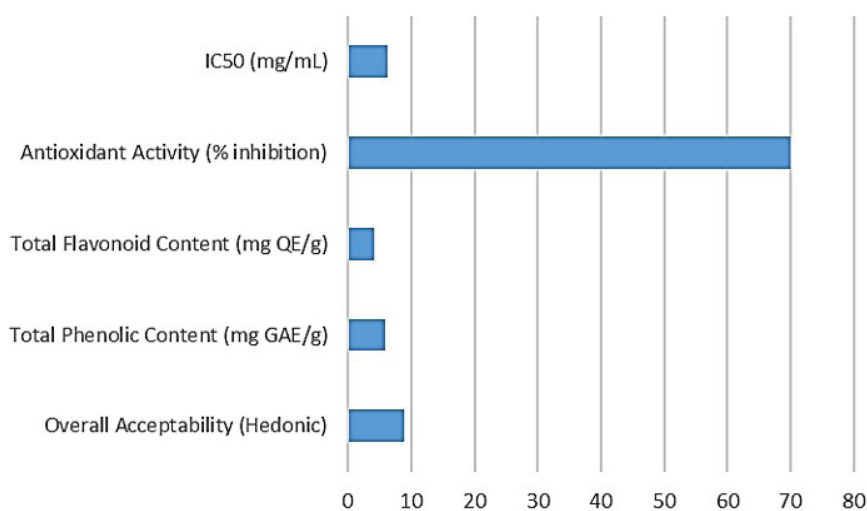


Figure 1: Optimal Concentration Results

Figure 1 illustrates that the combination ((70:30) showed best sensory qualities, maximum content of phytochemicals and the strongest antioxidant potential,

making it a promising functional food product aimed at boosting the immune system.

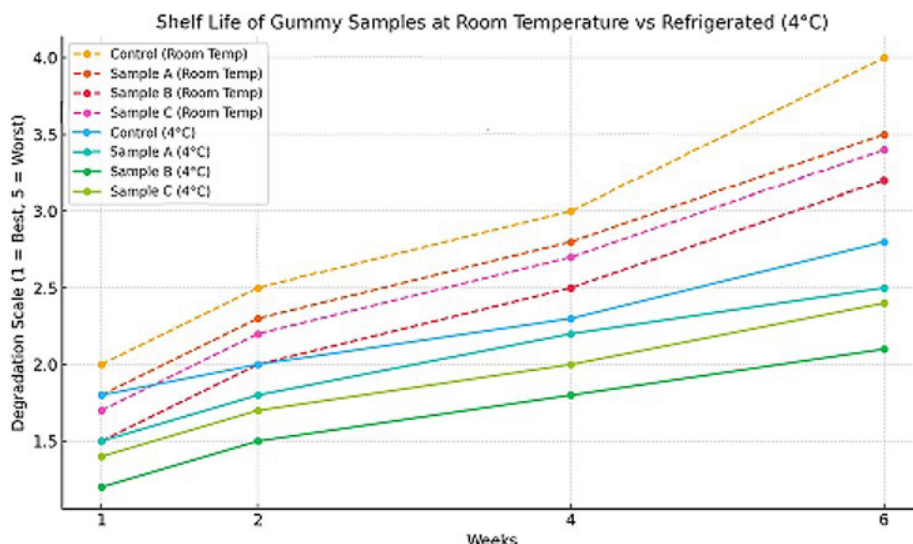


Figure 2: Shelf life of the gummy samples under room temperature vs Refrigerated (4 °C)

Figure 2 illustrates the shelf life of the gummy samples under room temperature and the under refrigerated conditions at 4°C for a six-week period. The figure indicates that, for quality with regard to texture and color, the degradation of the samples was slower when preserved at 4°C. Sample B, with a 70:30 pomegranate to water chestnut ratio, remained best quality when refrigerated, and there was very little degradation for six weeks compared with others. Samples stored at room temperature degraded far more rapidly, but Sample B still outperformed in shelf-life stability.

Determination of Optimal Concentration for Immunoprotective Activity

Pomegranate juice is very rich in bioactive compounds such as polyphenols, flavonoids, and antioxidants, which provide immune-boosting properties. Water chestnut extract also offers additional nutrients and minerals that may enhance general well-being. Sample B (70:30) showed the best results in terms of phytochemical content and antioxidant activity. Stronger phenolic and flavonoid contents are associated with greater immune-boosting capability because these compounds help the body's defense mechanisms.

Discussion

One of the main ingredients in confectionery items is candies such as jellies, gummy candy, chewing gums, marshmallows, etc. Being suitable to a vast array of consumers, they are by many considered as the most acceptable confections, particularly to children. The elastic property of gummy candy and gummy jellies makes them probably the most versatile confection products with various shapes, tastes, and odors (Pekdogan Goztok *et al.*, 2024). Gummies and jellies are a class of confections based on a hydrocolloid (sometimes called a stabilizer) that provides a network to hold relatively high moisture content sugar syrup. Historically, the term gummy (sometimes spelled as gummi) is considered for candies

made with gelatin, although this usage is not uniformly applied around the world (Hartel *et al.*, 2018). The most common hydrocolloids are gelatin, starch, and pectin. Each hydrocolloid contributes its own texture and organoleptic characteristics to the candy. Other hydrocolloids such as agar, gum arabic, carrageenan, etc. are normally used in combination with other hydrocolloids to add new characteristics and textures (Hartel *et al.*, 2018).

There is the upward trend to replace additives in foods. Therefore, the formulation of confectionary products solely dependent on natural ingredients with antioxidant properties could be of good help for the industry. Fruit juices and purées can give functional and organoleptic properties in jelly or gummy candies in a natural way. Pomegranate fruit and derivative products have been consumed in high amounts in the market due to their relation to healthy benefits (Cano-Lamadrid *et al.*, 2020). Among Asian people, its special taste and medical function make water chestnut one of the most popular Chinese foods. It has been used as a folk medicine for treating conditions, such as hypertension, chronic nephritis, constipation, pharyngitis, laryngitis, and enteritis (You *et al.*, 2007).

The current study results revealed that Sample B (70:30 pomegranate to water chestnut juice) possessed the most balanced sensory, phytochemical, and microbial properties, hence exhibiting the greatest functional benefits. Phytochemical assessment further evaluated that Sample B possessed the highest total phenolic (5.8 mg GAE/g) and flavonoid content (4.1 mg QE/g) responsible for its antioxidant activity with 70% inhibition and the lowest IC₅₀ value at 6.2 mg/mL. These findings showed that Sample B may indeed be a candidate for an immune-stimulant since the juice of the pomegranate contained larger amounts of bioactive compounds. Proximate analysis also found that Sample B had the lowest moisture content at 18.5%, the highest protein content at 1.3%, and the largest carbohydrate at 79.2%, meaning that it was the firmest in both texture and nutritional profile.

Texture analysis of the samples confirmed the structural integrity of Sample B with the highest hardness at 3.5 N, the highest chewiness at 0.8, and the highest cohesiveness at 0.7. Microbial stability also favored Sample B as having the highest shelf stability with the lowest microbial load value of 1500 CFU/g after 8 weeks. Sensory evaluation also preferred Sample B, scoring the highest in overall acceptability at 9, thus proving to have a well-balanced flavor and its texture and mouthfeel appealing enough for consumers to prefer it over others.

The developed gummies utilizing water chestnut and pomegranate juice provides a package of health benefits. Free radical overproduction and lipid peroxidation are involved in the pathogenesis of some chronic diseases, such as atherosclerosis, cardiac and cerebral ischemia, neurodegenerative disorders, carcinogenesis, diabetes, and rheumatic disorders. On the other hand, they play a major role in the aging process (You *et al.*, 2007). In the last couple of decades, interest in phenolic compounds extracted from fruits and vegetables has grown due to perceived health benefits. Existing literature describe the anticarcinogenic, antimutagenic, and cardioprotective effects of phenolic compounds to generally reflect their antioxidant activities in the process of eliminating free radicals and alleviating lipid peroxidation (You *et al.*, 2007). Pomegranate juice is a fruit juice rich in polyphenols with high antioxidant capacity. Pomegranate juice contains a rich array of bioactive compounds including polyphenols like ellagitannins and punicalagins with potent antioxidant and anti-inflammatory properties (Basu & Penugonda, 2009). These enhance immune function by reducing oxidative stress and inhibit inflammatory pathways. Another evidence that pomegranate juice is beneficial for the cardiovascular system, thereby indirectly affecting immune health due to systemic function improvement and concomitant risk reduction for diseases involving the immune system. Altogether, these properties may put pomegranate juice in the category of functional foods enhancing immune defense (Basu & Penugonda, 2009). Bioactive compounds such as phenolics and flavonoids provided a significant contribution to antioxidant capacity, meaning these gummies could be a choice for healthier confectionery productions. Future research could continue the optimization of natural sweeteners, such as honey, in large-scale production, assess consumer acceptability, and assess long-term health effects using clinical trials. Techniques for improving shelf life as well as more diverse formulation options that include various fruit juices may also be future extensions.

CONCLUSION

The developed gummies with the 70:30 ratio of pomegranate juice and water chestnut extract had the most balanced sensory, phytochemical, and functional properties. Sample B contained high phenolic and flavonoid content, antioxidant activity, and a stable shelf-life; therefore, it may be considered a fine material for any product aiming for the improvement of immune health

through functional foods. Such a formulation may be employed in healthier confectionery alternatives because it will attract consumers, who still keep on searching for versions of foods that are healthier but still desirable.

LIMITATIONS AND STRENGTHS

The limitations of the study may include:

- Shelf life is challenged to only two storage conditions: room temperature and refrigeration, respectively, which may not show a number of possible field conditions that can involve fluctuation in both temperature and humidity.
- Microbial analysis is conducted up to 8 weeks only. Risks of long-term spoilage or microbial activity might not have been revealed by such analysis in relation to prolonged storage or under different conditions.
- Thirty subjects participated in the sensory evaluation, which may not represent the preference of the entire population on a demographic or dietary basis.
- However, the study well adopts pomegranate and water chestnut extracts with antioxidants, phenolic, and flavonoids; hence, it offers a functional food product with improved health benefits, particularly for immune support.
- The study presents an in-depth analysis that consists of proximate composition, texture profiling, microbial stability, sensory evaluation, and phytochemical analysis which forms comprehensive overall understanding of the gummies' physical, chemical, and functional properties.
- Sensory evaluation shows an increased acceptability of consumers towards the taste, texture, and overall appeal, which demonstrates that the gummies may be fairly acceptable in the functional food market.

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