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Improving of Sweet Whey to Produce Healthy Beverages Incorporating with Some Plant Extracts

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ABSTRACT

The present study aims to develop various beverages using sweet whey, incorporating different proportions (25% and 50%) of licorice extract and tamarind extract. The chemical, physical, microbiological, and sensory properties of these beverages were evaluated at the initial stage (zero time) and during storage periods of 15, 30, and 45 days at a refrigeration temperature of 4±1°C. Results indicated that the whey-based tamarind beverages had higher protein and ash content. During storage, moisture content (%) significantly increased, while there was a notable decrease ($p \leq 0.05$) in the pH value of all whey-based beverages due to a rise in titratable acidity. Treatments with 25% and 50% licorice extract (T_1 and T_2) recorded the highest total sugar content, whereas the lowest level was observed in the treatment with 25% tamarind extract (T_3). The incorporation of licorice and tamarind extracts also led to an increase in mineral content. The L-values (lightness) significantly decreased with the addition of licorice and tamarind extracts, while the a-values (redness) and b-values (yellowness) significantly increased ($p \leq 0.05$) during the storage period. The total color index (ΔE* values) followed a similar trend as the L-values. Overall, the treatments enriched with licorice and tamarind extracts exhibited higher viscosity and water-holding capacity (WHC) compared to the control. Citric acid levels ranged from 0.17% to 0.31%, while lactic acid levels ranged from 0.28% to 0.53%. Whey-based beverages with licorice and tamarind extracts had a lower total plate count (TPC) compared to the control, and the yeast, mold, and coliform groups were below 10 colonies in all tested samples. The overall acceptability was highest for the whey-based beverage blended with 25% tamarind extract (T_3), followed by the treatment with 50% licorice extract (T_2).

1. Introduction

Plant-derived compounds offer proven health benefits, including cancer prevention, improved bone density, enhanced cardiovascular functions, reduced obesity, lower cholesterol levels, and delayed aging. Plants, fruits, and their derivatives are particularly recognized for promoting human health and preventing diseases. Notably, certain purified plant components and their combinations have also been shown to be effective in treating human diseases. Due to their high sugar content and affordability, licorice and tamarind have long been incorporated into human diets and are commonly used in products such as candy and processed beverages (Theophilou et al., 2017). Dairy industries today are actively seeking new product ideas and technologies to meet the increasing consumer demand for healthy foods while enhancing profitability. One promising approach is the development of products that use whey as a substitute for water, enriched with added nutrients, to serve as an excellent source of high-quality protein. Whey-based beverages are part of this category of innovative products, despite the fact that whey, a by-product of cheese production, is often considered waste or used as animal feed. Historically, whey has been regarded as a by-product, receiving scrutiny from environmental activists and technologists due to its strong contaminating properties.

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Dairy industries produce a large volume of whey as a by-product during cheese manufacturing, with global production reaching approximately 200 million tons per year. As an industrial wastewater, whey has a high biochemical oxygen demand (BOD) because of its organic compound content, making it one of the most environmentally harmful by-products in food production (Silva e Alves et al., 2018). However, despite its potential environmental impact, whey has significant potential as a valuable ingredient in the food industry due to its rich nutritional profile. The Protein Digestibility Corrected Amino Acid Score (PDCAAS) of whey protein is 1, the highest possible value, surpassing that of meat, wheat, and nuts. Additionally, whey protein exceeds the biological value (BV) of egg, meat, and soy protein (Smithers, 2015). Whey retains more than half of the nutrients found in milk, including salts, vitamins, lactose, enzymes, and proteins rich in essential amino acids with high bioavailability.

Furthermore, whey proteins are known to be precursors to biologically active peptides that produce various positive physiological effects on the human body, particularly impacting the immune, nervous, and cardiovascular systems. Growing environmental concerns from industries, businesses, government agencies, and environmentally conscious consumers have prompted research into the use of food industry by-products with functional and biological properties (Jeličić et al., 2008; Adriana et al., 2018; Kanchana et al., 2020). Like calories from food, calories from beverages containing sugars, carbohydrates, proteins, and fats also contribute to a person's daily energy intake. To maintain a healthy weight, it is crucial to manage the calories from both food and beverages as part of an individual's overall energy balance. Incorporating plant extracts into whey is an effective way to transform it from a by-product into a valuable product. Plant-based beverages using whey as an ingredient offer wholesome, nutritious drinks that support overall health and well-being. Storing whey-based beverages enhances their quality, nutritional value, acceptability, safety, digestibility, and overall shelf life (Jain et al., 2013; Maya & Ritu, 2016).

Licorice (Glycyrrhiza spp.), a medicinal plant of significant economic importance in the legume family, is widely used in pharmaceutical products. Extracts from this natural ingredient possess anti-tumor, anti-inflammatory, and antioxidant properties, making them valuable in the food industry for producing spices, sweeteners, beverages, confectionery, and functional foods. Licorice extract is also known for its surfactant and emulsifying properties. Its relatively high concentration of bioactive components, including flavonoids (e.g., 0.2-2.5% liquiritin), triterpenoid saponins (e.g., glycyrrhizin), coumarins, phenols, and polysaccharides (e.g., glycyrrhiza-polysaccharides), is one reason why licorice extract is considered an “essential herbal medicine” (Karkanis et al., 2018; Jiang et al., 2020; Nasiri et al., 2020 and Taarji et al., 2021).

Tamarind (Tamarindus indica L.) is a notable fruit belonging to the family Leguminosae and is native to tropical Africa. Its name is derived from the Persian word *tamar-i-hind*, meaning "date of India." Tamarind is now found in tropical and subtropical regions worldwide. The fruit of the tamarind tree is the most commonly used part and has a wide range of economic and industrial applications. In traditional medicine, tamarind is known for its laxative, expectorant, anti-inflammatory, and antioxidant properties. The pulp, which has a sour and cooling taste, can be consumed raw or processed into candies, ice cream, alcoholic beverages, soft drinks, concentrated juices, and seasonings. Research has shown that tamarind contains high levels of titratable acidity and organic acids such as tartaric, citric, and oxalic acids. It is also a good source of vitamins like riboflavin, niacin, and thiamin, although it contains lower levels of vitamins A and C. Additionally, tamarind is rich in essential minerals, including calcium, iron, phosphorus, magnesium, sodium, and potassium, making it a significant food in traditional diets (Parvez et al., 2003; De Caluwé et al., 2010; Hamacek et al., 2013; Rana et al., 2018; Abdeldaiem & Mokbel, 2022).

Thus, this study aimed to develop and evaluate the quality attributes, acceptability, and shelf life of whey-based beverages enriched with natural plant extracts of licorice and tamarind, which have sweetening properties.

2. Materials and Methods

Material

Fresh cow's sweet whey was obtained from the dairy plant at the Faculty of Agriculture, Cairo University. This whey, a by-product of Ras cheese production, was used throughout the current research. Licorice root and tamarind fruit were purchased from a local supplier in Cairo, Egypt.

Preparation of Whey-Based Beverages and Plant Extracts

Licorice and tamarind extracts were prepared by adding 295 g of licorice root or tamarind fruit to one liter of cold water, stirring for about 30 minutes, and soaking overnight (12 hours) in the refrigerator. The soaked mixtures were then blended and filtered through cheesecloth, followed by hand pressing to extract the free-running liquid. The obtained extracts were further filtered through a piece of cotton to remove any remaining fine particles. Whey-based plant beverages were prepared by blending sweet whey with licorice or tamarind extracts at 25% and 50% (v/v), following the method described by El-Gindy et al. (2015) with some modifications. The resulting blends were:

- C: 100% sweet whey (Control)
- T_1: 25% Licorice+75% sweet whey
- T_2: 50% Licorice extract +50 % sweet whey
- T_3: 25% Tamarind extract+75% sweet whey
- T_4: 50% Tamarind extract +50% sweet whey

All blends were thoroughly mixed and thermally treated at 85°C for 5 minutes, followed by rapid cooling. The final mixtures were then aseptically filled into sterilized 250 ml glass bottles and stored at 4 ± 1°C for 45 days. The entire process, including formulation, was carried out under aseptic conditions.

Analytical Methods

Chemical Analysis

The chemical composition of licorice, tamarind, and whey-based beverage treatments was determined in triplicate. Moisture, fat, protein, ash, and fiber content were analyzed according to AOAC (2007). The pH value was measured using a digital laboratory pH meter (HI 93 1400, Hanna Instruments), and titratable acidity (as lactic acid %) was determined following AOAC (2007) methods. Total soluble solids (TSS) content (measured in Brix) was recorded at 20°C using a refractometer (Abbe Hergestellt, DDR, Germany) as described by Niveadhitha et al. (2018). Total sugars, total reducing sugars, and total phenol content of the formulated beverages were analyzed following Sadasivam and Manickam (2008). Antioxidant activity (DPPH%) was determined according to Olivera et al. (2006).

Physico-Chemical Analysis

Viscosity was measured according to the method described by Vercet et al. (2002), while water holding capacity (WHC%) was determined using a centrifuge method as modified by Keogh and O'Kennedy (1998).

Mineral and Vitamin Determination

Major minerals, including calcium (Ca), phosphorus (P), potassium (K), sodium (Na), and magnesium (Mg), as well as minor minerals, such as zinc (Zn), iron (Fe), copper (Cu), and manganese (Mn), were determined using an atomic absorption instrument (Perkin-Elmer 3300, USA), following AOAC (2007) methods. Ascorbic acid (vitamin C) was analyzed according to Romeu-Nadal et al. (2006), vitamin B content was measured following Batifoulier et al. (2005), and β-carotene was determined according to Pupin et al. (1999).

Color Measurement

The color of the whey-based plant beverages was evaluated using a Colorimeter (CHROMA METER CR-400, Germany), which measured a^* (green/red), b^* (blue/yellow), L^* (lightness), and ΔE^* (total color index) values, following the method described by Wei et al. (2012).

Microbiological Analysis

Total plate count (TPC) was enumerated using plate count agar. Coliform bacteria were counted on violet red bile agar (Ronald, 2004), and yeast and mold counts were determined using yeast malt extract agar (Jay et al., 2005).

Statistical analysis

Statistical analysis carried out using one-way analysis of variance (ANOVA) followed by Duncan's Multiple Range Test. The significance differences were defined at ($P \leq 0.05$) using SAS program (SAS, 2008).

3. Results and Discussion

The chemical composition of licorice root and tamarind fruit is presented in Table 1. The moisture, protein, ash, and fat content ranged from 27.04% to 32.36%, 5.16% to 6.42%, 3.68% to 4.74%, and 3.63% to 4.81%, respectively, for licorice and tamarind. Tamarind fruit contained higher levels of crude fiber, total acidity, and fewer available calories compared to licorice, with acidity levels of 0.45% for licorice and 1.22% for tamarind.

The data indicate that both licorice and tamarind are rich sources of essential minerals, including calcium (Ca), phosphorus (P), potassium (K), sodium (Na), magnesium (Mg), and vitamins C, B1, and B2. The trace elements copper (Cu), zinc (Zn), and iron (Fe) act as cofactors for antioxidant enzymes, helping to protect the organism from oxygen free radicals generated during oxidative stress. Licorice and tamarind exhibit high antioxidant activity, attributed to their rich content of phenolic compounds such as tartaric acid, malic acid, and triterpenes, with the latter being more prominent in tamarind (El-Gindy et al., 2015; Gamal et al., 2020; Tavanappanavar et al., 2024).

Table 1. The chemical composition of licorice and tamarind plant used in manufacture of whey-based beverages

Character assessed	Licorice	Tamarind
Moisture (%)	32.36[a]	27.04[b]
Protein (%)	5.16[a]	6.42[b]
Ash (%)	3.68[b]	4.74[a]
Fat (%)	4.81[a]	3.63[b]
Crude fiber (%)	7.06[b]	10.32[a]
Total acidity (%)	0.45[b]	1.22[a]
pH value	6.42[a]	5.33[b]
Calories/100g	267.77[a]	233.31[b]
Minerals: mg/100g Ca	1661.2[b]	2002.77[a]
P	261.42[b]	447.34[a]
Cu	1.88[b]	2.35[a]
Mg	220.14[b]	257.38[a]
Zn	3.98[b]	5.46[a]
Fe	12.04[a]	11.74[b]
K	535.01[b]	550.27[a]
Na	115.02[b]	136.22[a]
Vitamin C (mg/100g)	5.28[b]	18.36[a]
Thiamin (B1) (µg/100g)	341[b]	452[a]
Riboflavin(B2) (mg/100g)	292[b]	348[a]
ß- carotene (mg/100g)	96[a]	92[a]
Total phenolic (%)	45.12[b]	80.78[a]
DPPH (%)	18.64[b]	74.22[a]

Means followed by the same lower case in each row indicate no significant difference ($P \leq 0.05$).

Chemical Composition of Whey-Based Beverages

The chemical characteristics of whey-based plant beverages are presented in Table 2. The moisture content is higher in the control (whey beverage only) compared to whey-based plant beverages. Due to the higher total solids content in tamarind than licorice, tamarind extract beverages have lower moisture content (%) than licorice extract beverages. Additionally, as the extract level increases, the moisture percentage decreases. During the storage period, the moisture content (%) significantly increased, possibly due to the solubilization of solid components in more acidic environments (Sakhale et al., 2012). Ahmed et al. (2023) observed that whey beverages absorbed moisture, likely as a result of the bottles being opened for sample testing. Furthermore, whey-based tamarind beverages exhibited higher protein and ash content compared to other treatments. These values (protein and ash) significantly decreased during cold storage, potentially due to proteolysis and the use of these components as metabolic resources for the growth of microorganisms, which reduces the total solid content. In contrast, all treatments showed a significant increase in total soluble solids (TSS) content during the storage period from 0 to 45 days (Table 2).

Table 2. Chemical composition of whey-based beverages incorporating with licorice and tamarind extract

Cold storage (day)	C	T_1	T_2	T_3	T_4
			Moisture (%)		
Fresh	93.47^{Da}	93.29^{Db}	93.23^{Db}	93.02^{Dc}	92.90^{Dd}
15	93.94^{Ca}	93.77^{Cb}	93.50^{Cc}	93.31^{Cd}	93.17^{Ce}
30	94.20^{Ba}	94.01^{Bb}	93.70^{Bc}	93.53^{Bd}	93.32^{Be}
45	94.43^{Aa}	94.28^{Ab}	93.84^{Ac}	93.72^{Ad}	93.49^{Ae}
			Protein (%)		
Fresh	0.37^{Ad}	0.39^{Ac}	0.40^{Ab}	0.41^{Ab}	0.43^{Aa}
15	0.35^{Bd}	0.37^{Bc}	0.38^{Bc}	0.39^{Bb}	0.41^{Ba}
30	0.33^{Cd}	0.36^{Cc}	0.37^{Cc}	0.38^{Cb}	0.41^{Ca}
45	0.31^{De}	0.35^{Dd}	0.36^{Dc}	0.38^{Db}	0.40^{Da}
			Ash (%)		
Fresh	0.99^{Ab}	0.98^{Abc}	0.99^{Ab}	1.00^{Ab}	1.03^{Aa}
15	0.98^{Bb}	0.97^{Bb}	0.98^{Bb}	0.98^{Bb}	1.00^{Ba}
30	0.97^{Cb}	0.96^{cb}	0.97^{Cb}	0.98^{Ca}	0.99^{Ca}
45	0.97^{Cb}	0.95^{Cc}	0.96^{Cbc}	0.97^{Cb}	0.98^{Ca}
			T.S.S (ºBrix)		
Fresh	4.0^{Be}	4.2^{Bd}	4.5^{Bc}	6.0^{Bb}	7.5^{Ba}
15	4.1^{Be}	4.3^{Bd}	4.6^{Bc}	6.0^{Bb}	7.6^{Ba}
30	4.2^{Ae}	4.4^{Ad}	4.7^{Ac}	6.1^{Ab}	7.7^{Aa}
45	4.2^{Ae}	4.5^{Ad}	4.7^{Ac}	6.2^{Ab}	7.7^{Aa}

-T.S.S: Total soluble solids
-Means followed by the same lower case in each row indicate no significant ($P \leq 0.05$) effect of treatment.
-Means followed by the same upper case in the same column indicate no significant ($P \leq 0.05$) effect of storage.

The increase in TSS could be attributed to the conversion of insoluble polysaccharides into reduced sugars. Alane et al. (2017) noticed a similar upward trend in TSS in a whey and mango plant-based drink, where the concentration of TSS increased from 15 to 17.2° Brix after 30 days of storage. These results are in the same line as those found by Bhavsagar et al. (2010); David & Kumar, (2015) and Ahmed et al. (2023).

Titratable Acidity (%) and pH Values

The effect of added licorice and tamarind extract on titratable acidity (TA) and pH values during storage at 4°C is illustrated in Table 3. TA was higher in tamarind whey-based beverages than licorice whey beverages and increased significantly with a higher percentage of added extract. During storage, the TA of all whey-based beverages gradually increased up to 45 days. Concurrently, the pH values of all beverages decreased significantly ($p \leq 0.05$) due to the increase in titratable acidity, which has an inverse relationship with pH. This rise in acidity and decline in pH primarily contribute to the transformation of proteins, lactose, and other carbohydrates into amino acids and organic acids (primarily lactic acid) during storage. These findings align with the results reported by Chavan et al. (2015), El-Baily

2016), Aly et al. (2019), and Kanchana et al. (2020).

Sugars Content

Table 4 presents the total, reducing, and non-reducing sugars of whey-based beverages when fresh and during the cold storage period (45 days). The highest total sugars content was observed in treatments T_1 and T_2 (6.93% and 8.74%, respectively), while the lowest level was recorded in treatment T_3 with 25% tamarind extract (3.67%).

Reducing sugars were also higher in licorice beverage treatments compared to the control, which had the lowest reducing sugars initially. However, the reducing sugars increased during the storage period. This progressive increase in reducing sugars can be attributed to the conversion of sugars (disaccharides) into reducing sugars monosaccharides) through acid hydrolysis, leading to a decrease in total and non-reducing sugars in the whey beverages. These findings are consistent with the results reported by Yonis et al. (2014), Pandey & Ojha (2020), and Ahmed et al. (2023).

Table 3. Titratable acidity (%) and pH values of whey-based beverages incorporating with licorice and tamarind extract

Cold storage (day)	C	T_1	T_2	T_3	T_4
			Titratable acidity (%)		
Fresh	0.38^{Dc}	0.35^{Dd}	0.36^{Dd}	0.47^{Db}	0.51^{Da}
15	0.43^{Cc}	0.40^{Cd}	0.41^{Cd}	0.54^{Cb}	0.57^{Ca}
30	0.49^{Bc}	0.46^{Bd}	0.50^{Bc}	0.57^{Bb}	0.61^{Ba}
45	0.51^{Ad}	0.50^{Ad}	0.57^{Ab}	0.60^{Ab}	0.63^{Aa}
			pH values		
Fresh	5.61^{Ac}	5.97^{Aa}	5.85^{Ab}	4.94^{Ad}	4.63^{Ae}
15	4.87^{Bc}	5.63^{Ba}	5.13^{Bb}	4.49^{Bd}	4.16^{Be}
30	4.52^{Cc}	5.41^{Ca}	4.82^{Cb}	4.31^{Cd}	4.05^{Ce}
45	4.49^{Dc}	5.22^{Da}	4.73^{Db}	4.13^{Dd}	3.88^{De}

Means followed by the same lower case in each row indicate no significant ($P \leq 0.05$) effect of treatment.
Means followed by the same upper case in the same column indicate no significant ($P \leq 0.05$) effect of storage.

Table 4. Sugars content of whey-based beverages incorporating with licorice and tamarind extract

Cold storage (day)	C	T_1	T_2	T_3	T_4
			Total sugars (%)		
Fresh	4.68^{Ad}	6.93^{Ab}	8.74^{Aa}	3.67^{Ae}	6.53^{Ac}
15	4.54^{Bd}	6.72^{Bb}	8.61^{Ba}	3.50^{Be}	6.31^{Bc}
30	4.31^{Cd}	6.58^{Cb}	8.46^{Ca}	3.41^{Ce}	6.10^{Cc}
45	4.12^{Dd}	6.37^{Db}	8.21^{Da}	3.22^{De}	5.95^{Dc}
			Reducing sugars (%)		
Fresh	1.76^{De}	5.53^{Db}	7.53^{Da}	2.84^{Dd}	4.61^{Dc}
15	1.78^{Ce}	5.57^{Cb}	7.62^{Ca}	2.86^{Cd}	4.65^{Cc}
30	1.81^{Be}	5.61^{Bb}	7.65^{Ba}	2.90^{Bd}	4.70^{Bc}
45	1.89^{Ae}	5.64^{Ab}	7.68^{Aa}	2.94^{Ad}	4.76^{Ac}
			Non-reducing sugars (%)		
Fresh	2.93^{Aa}	1.41^{Ac}	1.21^{Ad}	0.83^{Ae}	1.92^{Ab}
15	2.76^{Ba}	1.15^{Bc}	0.99^{Bd}	0.64^{Be}	1.66^{Bb}
30	2.50^{Ca}	0.97^{C}	0.81^{Cd}	0.51^{Ce}	1.40^{Cb}
45	2.23^{Da}	0.73^{Dc}	0.53^{Dd}	0.28^{De}	1.19^{Db}

Means followed by the same lower case in each row indicate no significant ($P \leq 0.05$) effect of treatment.
Means followed by the same upper case in the same column indicate no significant ($P \leq 0.05$) effect of storage.

Minerals Determination

The mineral content (mg/100 ml) analysis revealed significant differences ($P \leq 0.05$) among all treatments of whey-based beverages with licorice and tamarind extract (Table 5). The addition of licorice and tamarind extract resulted in an increase in mineral content for all treatments compared to the control, except for calcium. This can be attributed to the abundance of minerals in licorice and tamarind plants (Atallah & Gemiel, 2020). Lactose, phosphorus, and vitamins are known to enhance calcium availability from milk.

Color Parameters

Color parameters significantly influence consumer acceptance of whey-based beverages. As illustrated in Table 6, the lightness (L-values) of the tested beverages ranged from 32.68 to 56.94. The addition of licorice and tamarind extract notably decreased L-values, with T_4 exhibiting the lowest lightness throughout the storage period (45 days). This trend is likely attributed to the presence of proteins, fat, and calcium, which can have a whitening effect on milk-based beverages. Conversely, the use of licorice and tamarind extract increased both a-values and b-values. The control exhibited a greenish color shade (a-values = -2.31), while all prepared whey beverages displayed varying degrees of yellow color (b-values). A slight blue color shade (negative b-values) was observed in the control. Treatment T_2 exhibited the most intense yellow color. Both a- and b-values increased significantly ($p \leq 0.05$) during the storage period. The total color index (ΔE*-values) followed a similar pattern to L-values. The results indicate that the addition of components caused statistically significant ($p \leq 0.05$) changes in color attributes, but these changes were not significant enough to adversely affect the overall color appearance of the product. Furthermore, the presence of proteins in the whey used is essential for enhancing consumer color acceptance. These findings align with the results reported by Jawarska et al. (2014), Liutkevicius et al. (2016), and Gab-Allah & Shehta (2020).

Table 5. Minerals content (mg/100ml) of whey-based beverages incorporating with licorice and tamarind extract

Mineral (mg/100g)	C	T_1	T_2	T_3	T_4
Ca	67.56^{a}	48.11^{b}	61.23^{a}	59.52^{a}	64.17^{a}
P	22.24^{c}	34.23^{b}	37.78^{b}	48.24^{a}	55.13^{a}
K	37.55^{c}	43.83^{b}	58.45^{a}	50.78^{ab}	65.12^{a}
Na	21.23^{c}	29.14^{b}	34.21^{a}	32.54^{ab}	37.89^{a}
Mg	0.89^{c}	1.13^{b}	1.24^{a}	1.19^{b}	1.32^{a}
Zn	0.03^{a}	0.05^{a}	0.06^{a}	0.05^{a}	0.07^{a}
Fe	0.13^{a}	0.16^{a}	0.17^{a}	0.15^{a}	0.16^{a}
Cu	0.33^{a}	0.40^{a}	0.42^{a}	0.40^{a}	0.41^{a}
Mn	0.05^{a}	0.06^{a}	0.07^{a}	0.06^{a}	0.06^{a}

Means followed by the same lower case in each row indicate no significant ($P \leq 0.05$) effect of treatment

Viscosity and Water Holding Capacity (WHC)

Table 7 presents the viscosity and WHC values of the whey-based plant beverages. Viscosity values ranged from 1.6 to 3.2cP, while WHC values ranged from 92.79 to 94.07%. Treatments enriched with licorice and tamarind extract exhibited higher viscosity and WHC values compared to the control due to their higher percentage of total solids and crude fibers, which act as natural thickeners and improve water-binding capacity. Cold storage resulted in significant variations ($p \leq 0.05$) in viscosity values across all treatments. This observation can be interpreted to the protein hydration and presence of large amount of particles increased the flow resistance, resulting in an increase in apparent viscosity; while the WHC values significantly decreased due to the development of acidity through storage period. These finding are in agreement with Aly et al. (2019); Gab-Allah & Shehta (2020); Kanchana et al. (2020) and Abdeldaiem & Mokbel (2022).

Table 6. Color parameters of whey-based beverages with licorice and tamarind extract

Cold storage (day)	C	T_1	T_2	T_3	T_4
			*L**		
Fresh	56.94^{Da}	42.01^{Db}	35.05^{Dd}	38.56^{Dc}	32.68^{De}
15	59.68^{Ca}	43.74^{Cb}	35.36^{Cd}	40.67^{Cc}	34.39^{Ce}
30	61.12^{Ba}	44.08^{Bb}	35.51^{Bd}	41.10^{Bc}	35.21^{Bd}
45	62.42^{Aa}	45.48^{Ab}	36.13^{Ad}	42.78^{Ac}	35.67^{Ad}
			*a**		
Fresh	-2.31^{De}	1.87^{Db}	2.98^{Da}	1.10^{Dd}	1.54^{Dc}
15	-2.48^{Ce}	2.02^{Cc}	3.71^{Ca}	1.54^{Cd}	2.11^{Cb}
30	-2.79^{Bd}	2.86^{Bc}	4.44^{Ba}	2.81^{Bc}	3.78^{Bb}
45	-3.10^{Ae}	3.74^{Ad}	5.46^{Aa}	4.22^{Ac}	5.19^{Ab}
			*b**		
Fresh	-0.07^{Dd}	13.56^{Db}	14.14^{Da}	9.17^{Dc}	9.76^{Dc}
15	0.68^{Ce}	14.25^{Cb}	15.68^{Ca}	10.34^{Cd}	10.35^{Cc}
30	1.18^{Bd}	14.73^{Bb}	17.23^{Ba}	11.97^{Bc}	11.91^{Bc}
45	2.43^{Ad}	15.21^{Ab}	18.61^{Aa}	13.62^{Ac}	13.47^{Ac}
			ΔE*		
Fresh	25.57^{Aa}	20.21^{Ac}	15.11^{Ad}	24.18^{Ab}	20.32^{Ac}
15	25.37^{Ba}	19.19^{Bc}	13.52^{Be}	23.43^{Bb}	19.13^{Bd}
30	25.32^{Ca}	18.56^{Cc}	11.14^{Ce}	20.80^{Cb}	16.21^{Cd}
45	25.28^{Da}	17.93^{Db}	8.78^{Dd}	18.17^{Db}	13.29^{Dc}

-L* =lightness a*= redness b*= yellowness ΔE*= total color index
-Means followed by the same lower case in each row indicate no significant ($P \leq 0.05$) effect of treatment.
-Means followed by the same upper case in the same column indicate no significant ($P \leq 0.05$) effect of storage.

Organic acids

The obtained results in Figure1. showed citric and lactic acid (%) development in whey-based plant beverages. Citric acid ranged between 0.17-0.31%, while lactic acid ranged between 0.28-0.53%, As the level of added licorice or tamarind extract increase, the percentage of organic acids increase too.

Table 7. Viscosity (cP) and water holding capacity (WHC %) of whey-based beverages incorporating with licorice and tamarind extract

Cold storage (day)	**C**	**T_1**	**T_2**	**T_3**	**T_4**
			Viscosity (cP)		
Fresh	1.6^{Cd}	2.1^{Cc}	2.6^{Cb}	2.5^{Cb}	3.2^{Ca}
15	1.7^{Bd}	2.3^{Bc}	2.6^{Bb}	2.6^{Bb}	3.3^{Ba}
30	1.8^{Ad}	2.5^{Ac}	2.7^{Ab}	2.7^{Ab}	3.4^{Aa}
45	1.8^{Ad}	2.6^{Ac}	2.9^{Ab}	2.8^{Ab}	3.5^{Aa}
			WHC (%)		
Fresh	92.79^{Ac}	93.05^{Ab}	93.23^{Ab}	93.47^{Ab}	94.07^{Aa}
15	91.55^{Bd}	91.67^{Bc}	92.31^{Bb}	92.54^{Bb}	93.12^{Ba}
30	90.13^{Cd}	90.56^{Cc}	91.32^{Cb}	91.40^{Cb}	92.11^{Ca}
45	89.84^{Dd}	90.05^{Dc}	90.78^{Db}	91.01^{Db}	91.89^{Da}

Means followed by the same lower case in each row indicate no significant ($P \leq 0.05$) effect of treatment.
Means followed by the same upper case in the same column indicate no significant ($P \leq 0.05$) effect of storage.

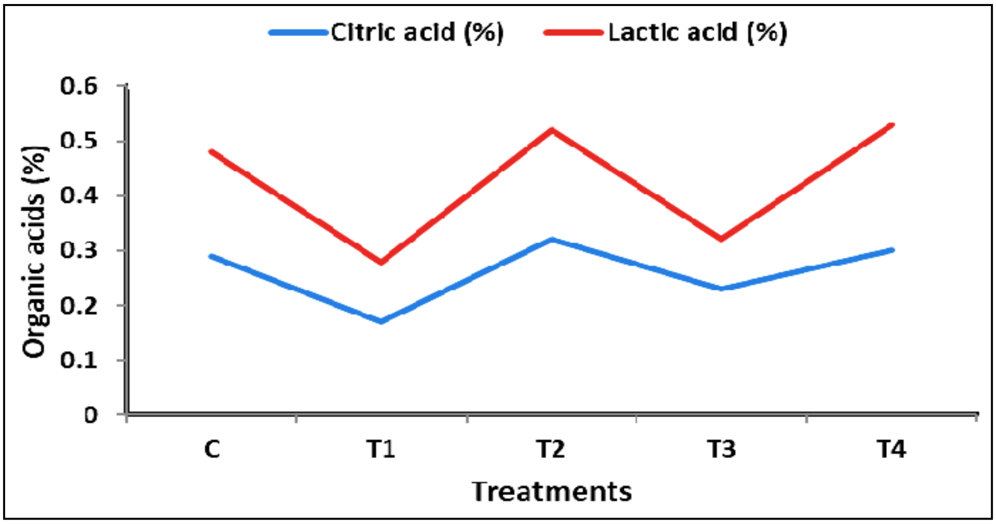

Figure 1. Organic acids (%) of whey-based beverages incorporating with licorice and tamarind extract

Microbiological Analysis

Periodically, whey-based beverage samples were analyzed for total plate count (TPC). The initial TPC for all fresh samples was <10^3 CFU/ml. However, viable counts gradually increased throughout the storage period, reaching 27.3 × 10^4, 15.5 × 10^4, 13.0 × 10^4, 17.0 × 10^4, and 13.6 × 10^4 CFU/ml in beverage samples C, T_1, T_2, T_3, and T_4, respectively, after 45 days of storage. This increase in TPC can be attributed to the presence of proteins and lactose sugar in whey, which can support bacterial growth during storage. However, enriched whey-based beverages with licorice and tamarind extract exhibited lower TPC compared to the control (C). This is likely due to the antimicrobial properties of these extracts (Ismail et al., 2011; Sakhale et al., 2012; Sharma et al., 2020). Yeast, mold, and coliform group counts were <10 CFU/ml in all tested samples, indicating high hygienic conditions during processing and storage. Additionally, the low pH (~4.50) of the whey-based beverages and the intensity of the heat treatments applied may have contributed to growth inhibition. Similar results were reported by Akande & Ojekemi (2013) and Ahmed et al. (2023).

Table 8. Microbiological analysis (CFU /ml) of whey-based beverages incorporating with licorice and tamarind extract

Cold storage (day)	C	T_1	T_2	T_3	T_4
Total plate count (TPC)					
Fresh	<10^3	<10^3	<10^3	<10^3	<10^3
15	21.1×10^3	17.8×10^3	14.1×10^3	19.8×10^3	13.7×10^3
30	8.8×10^4	4.0×10^4	3.6×10^4	8.5×10^4	6.0×10^4
45	27.3 ×10^4	15.5×10^4	13.0×10^4	17×10^4	13.6×10^4
Yeast &mold					
Fresh	N.D	N.D	N.D	N.D	N.D
15	<10	<10	<10	<10	<10
30	<10	<10	<10	<10	<10
45	<10	<10	<10	<10	<10
Coliform group					
Fresh	N.D	N.D	N.D	N.D	N.D
15	<10	N.D	N.D	N.D	N.D
30	<10	<10	<10	<10	<10
45	<10	<10	<10	<10	<10

-Means followed by the same lower case in each row indicate no significant ($P \leq 0.05$) effect of treatment.
-Means followed by the same upper case in the same column indicate no significant ($P \leq 0.05$) effect of storage.
- N.D: Not detected

Sensory Evaluation

The sensory properties of whey-based plant beverages were evaluated as shown in Table 9. Treatment T_3 consistently received significantly higher scores for all tested quality attributes (appearance, flavor, taste, color, and overall acceptability) compared to other treatments. The control was rated as the least acceptable sample due to its lower scores. The sensory quality attributes of all treatments declined over time, particularly after 15 days of storage. This decline can be attributed to changes in the beverage during storage, such as browning, increased acidity, and alterations in taste and flavor. The decrease in overall acceptability scores may have been primarily caused by these factors. Treatment T_3 (with 25% tamarind extract) exhibited the highest overall acceptability score (8.1 points) followed by T_2 with 50% licorice extract (7.5 points) at the end of the storage period (45 days). These findings are consistent with the results reported by Yonis et al. (2014) and Gab-Allah & Shehta (2020).

Table 9. Sensory properties of whey-based beverages incorporating with licorice and tamarind extract

Cold storage (day)	C	T_1	T_2	T_3	T_4
			Appearance (10)		
Fresh	6.6^{Ae}	7.2^{Ad}	8.2^{Ab}	8.6^{Aa}	7.7^{Ac}
15	6.5^{Ae}	7.0^{Ad}	8.0^{Ab}	8.5^{Aa}	7.5^{Ac}
30	6.1^{Be}	6.4^{Bd}	7.6^{Bb}	7.9^{Ba}	7.1^{Bc}
45	5.6^{Ce}	6.2^{Cd}	7.1^{Cb}	7.6^{Ca}	6.6^{Cc}
			Flavor (10)		
Fresh	6.6^{Be}	7.1^{Bd}	8.1^{Bb}	8.7^{Ba}	7.6^{Bc}
15	7.5^{Ad}	8.2^{Ac}	8.6^{Ab}	9.1^{Aa}	8.2^{Ac}
30	7.1^{Bd}	7.7^{Bc}	8.1^{Bb}	8.6^{Ba}	7.6^{Bc}
45	6.5^{Cd}	7.2^{Cb}	7.4^{Cb}	8.0^{Ca}	6.7^{Cc}
			Taste (10)		
Fresh	6.7^{Be}	7.2^{Bd}	8.2^{Bb}	8.6^{Ba}	7.7^{Bc}
15	7.6^{Ad}	8.2^{Ac}	8.7^{Ab}	9.2^{Aa}	8.2^{Ac}
30	7.2^{Bd}	7.6^{Bc}	8.2^{Bb}	8.7^{Ba}	7.7^{Bc}
45	6.6^{Ce}	7.0^{Cc}	7.6^{Cb}	8.2^{Ca}	6.8^{Cd}
			Color (10)		
Fresh	6.5^{Ae}	7.2^{Ad}	8.3^{Ab}	8.5^{Aa}	7.8^{Ac}
15	6.7^{Ae}	7.4^{Ad}	8.4^{Ab}	8.7^{Aa}	8.1^{Ac}
30	6.2^{Be}	6.6^{Bd}	7.8^{Bb}	8.2^{Ba}	7.6^{Bc}
45	5.8^{Ce}	6.2^{Cd}	7.4^{Cb}	7.7^{Ca}	6.7^{Cc}
			Overall acceptability (10)		
Fresh	6.6^{B}	7.1^{Bd}	8.1^{Bb}	8.6^{Ba}	7.6^{Bc}
15	6.9^{Ae}	7.4^{Ad}	8.3^{Ab}	8.7^{Aa}	7.7^{Ac}
30	6.5^{Ce}	7.2^{Cd}	7.7^{Cb}	8.2^{Ca}	7.3^{Cc}
45	6.2^{De}	6.5^{Dd}	7.5^{Db}	8.1^{Da}	7.0^{Dc}

Means followed by the same lower case in each row indicate no significant ($P \leq 0.05$) effect of treatment.
Means followed by the same upper case in the same column indicate no significant ($P \leq 0.05$) effect of storage.

4. Conclusion

In this study, whey is successfully used to develop whey-based plant beverages with excellent sensory and nutritional qualities as well as storage stability. The beverage possesses high color, flavor and stability characteristics. Incorporating licorice and tamarind extract with whey creates a nutritious beverage with better shelf life. The beverage has a shelf life of approximately 45 days when refrigerated. The overall acceptability of whey-based plant beverage blending with 25% tamarind extract (T_3) was found to be superior followed by (T_2) with 50% licorice extract. Based on the findings, it may be concluded that whey can be utilized with licorice and tamarind extract to develop whey-based beverages.

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