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Effect of Different Air Oven Temperatures on Chemical, Physical, and Microbial Properties of Dried Bio-Yoghurt Product

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Abstract: The aim of this study was to compare the physical, chemical, and microbiological features of bio-yoghurt that had been air-oven-dried at three temperatures (40, 50, and 60 °C) to those of fresh bio-yoghurt. The results showed that drying bio-yoghurt at 40–60 °C decreased the number of probiotic starter bacteria in dried yoghurt products compared to fresh bio-yoghurt. The dried yoghurt's moisture, protein, fat, carbohydrate, and ash contents were 4.16–4.55%, 38.22–40.02%, 1.33–1.43%, 47.94–49.45%, and 6.37–6.55%, respectively. The pH and total acidity levels of dried yoghurt were within acceptable ranges at various temperatures and storage durations. At different temperatures, the viscosity values of the products decreased by 620–550 cp; however, the hygroscopicity values remained constant. During a 90-day storage period, the dried yoghurt product's physical, chemical, and microbiological characteristics remained within acceptable levels. Using a drying temperature of 40–50 °C kept the number of live bacteria below acceptable ranges during storage periods. *Lactobacillus acidophilus* counts were 6.75 and 6.70 log CFU/g, respectively, whereas *Bifidobacterium bifidum* numbers were 6.66 and 6.08 log CFU/g, respectively. In conclusion, drying bio-yoghurt in an air oven at 40–50 °C provided a dried product with a high number of viable probiotic bacteria and satisfactory physicochemical characteristics after 3 months.

Keywords: dried yoghurt; probiotic bacteria; dried yoghurt properties; air oven

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1. Introduction

Yoghurt is a widely recognized food product that is produced through the process of milk fermentation. Yoghurt is a nutritionally rich substance that encompasses a diverse array of nutrients. Furthermore, it is considered a healthful food due to its inclusion of lactic acid bacteria. The bacterial microorganisms exhibit the ability to synthesize multiple bioactive compounds that contribute to the enhancement of the host's physiological well-being [1]. Nevertheless, yoghurt is a highly perishable product with a limited shelf life of no more than one month, resulting in the deterioration of substantial quantities [2]. Yoghurt exhibits a limited duration of freshness, particularly when subjected to a temperature of 25 °C. Therefore, it necessitates preservation at a temperature of 4 °C [3]. This entails substantial financial expenditures for the purposes of storage, transportation, and marketing. In countries with high temperatures, such as Iraq, where there is a notable increase in ambient temperatures, the difficulties associated with yoghurt storage are exacerbated. Elevated temperatures expedite the degradation process, thereby emphasizing the necessity of refrigerating yoghurt at a reduced temperature. This presents supplementary economic challenges in relation to the storage, transportation, and marketing aspects, as it necessitates the utilization of specialized refrigeration facilities and systems to uphold the desired temperature [4].

Numerous techniques have been utilized to dehydrate yoghurt with the aim of addressing production obstacles and enhancing its transportation and commercialization. The techniques employed in this study encompass freeze drying, spray drying, hot air drying, and various other methodologies [5,6]. The composition of yoghurt undergoes alterations during the drying process, which are contingent upon the specific technology employed and the prevailing drying conditions. These modifications have the potential to induce substantial alterations in the rheological characteristics and viability of starter bacteria in contrast to unpreserved yoghurt. As a result, this could potentially reduce the potential health advantages for consumers and impact the overall acceptance of the end product [7,8]. The efficacy of storing starter yoghurt cultures for extended periods was observed to be higher when maintained at a temperature range of 5–10 °C compared to storage at ambient room temperature. The viability of bacterial strains in dried yoghurt, which underwent either freeze-drying or spray-drying processes from milk cultures, was found to be improved by storing them at lower temperatures. The spray-dried culture powders of *Lactobacillus. acidophilus* and *Lactobacillus helveticus* exhibited remarkable lactic acid production, as evidenced by viable plate counts of approximately 10^9 colony-forming units per gram [5].

Yoghurt is produced through the fermentation of milk by lactic acid bacteria, which possess advantageous properties for the well-being of consumers. The microbial inoculum utilized in the production of yoghurt comprises two distinct bacterial strains, namely *Streptococcus thermophilus* and *Lactobacillus delbrueckii* subsp. *bulgaricus* [9]. In recent years, a number of probiotic bacteria have been employed in the manufacturing of bio- yoghurt with the aim of augmenting its health-enhancing characteristics. Within the microbial assemblage, there exist specific bacterial strains, namely *Lactobacillus acidophilus* and *Bifidobacterium bifidum* [10]. The new Codex standard currently uses the following definition for yoghurt product: a product made from *St. thermophilus* and lactobacilli other than *Lb. bulgaricus* [1]. The bacterial starter cultures facilitate the production of diverse metabolic byproducts, such as organic acids, flavor compounds, and bacteriocins. The chemical constituents of yoghurt can undergo alterations as a result of the temperatures employed during the process of yoghurt dehydration, resulting in a reduction in the nutritional and health benefits of the dried yoghurt [11].

The objective of the current investigation was to transform bio-yoghurt into dried yoghurt and evaluate the physical, chemical, and microbiological properties of the bio-yoghurt product by air drying it at different temperatures while maintaining viable numbers of probiotic bacteria during storage periods.

2. Materials and Methods

2.1. Raw Materials

The skimmed milk utilized in this study was obtained from the Agricultural Research Station, College of Agriculture, University of Basrah, Basra City, Iraq. The composition of the skimmed milk was determined to be 91% water, 4.2% carbohydrates (specifically lactose), 3.9% protein, and 0.9% ash (comprising minerals). The probiotic starter culture was acquired from the laboratories of Chr. Hansen A/S in Denmark. It is composed of a combination of *Lactobacillus acidophilus* La-5, *Bifidobacterium bifidum* Bb-12, and *Streptococcus thermophilus* in equal proportions (1:1:1). MRS-sorbitol (MRS basal medium devoid of glucose) was prepared by combining 10 mL of membrane-filtered sterile solutions containing 10% D-sorbitol with 90 mL of the basal medium, resulting in a final concentration of 1% sorbitol. Filter-sterilized MRS-NNLP (stock solutions of the NNPL components, namely neomycin sulfate at a concentration of 100 mg/L, paromomycin at 200 mg/L, nalidixic acid at 15 mg/L, and LiCl at 3 g/L) is commercially available from Sigma-Aldrich in Germany. Additionally, M17 culture media were utilized to activate the starter culture and enumerate the bacterial population during the production of yoghurt and the subsequent storage periods. The chemicals utilized in the experiment were of analytical grade [12].

2.2. Yoghurt Production

A total volume of 1000 mL of skimmed milk was utilized in the process of yoghurt production. The sample was subjected to thermal treatment at a temperature of 95 °C for a duration of 15 min. After reducing the temperature to 40 °C, a 5% concentration of an activated starter culture containing 10^9 CFU/g of lactic acid bacteria was introduced. The mixture was then incubated at 40 °C until it achieved a pH level of 4.6. Subsequently, the sample was subjected to refrigeration at a controlled temperature range of 6–8 °C for a duration of 24 h, during which the subsequent tests were conducted [12].

2.2.1. Yoghurt Analysis

Chemical Composition

The yoghurt samples underwent chemical composition analysis following a storage period of one day. The moisture content was assessed by exposing the samples to a controlled hot air oven at a temperature of 105 ± 2 °C until a consistent weight was attained. The total protein content was determined using the micro-Kjeldahl method, which involves multiplying the nitrogen content by a factor of 6.38. Ash content was determined by heating samples in the furnace oven at 621 °C for 16–20 h. The Gerber method was employed to quantify the overall lipid concentration. A 10 g sample of yoghurt or dried yoghurt was subjected to hydrolysis using 10 mL of sulfuric acid (H_2SO_4) at a temperature range of 60–65 °C. After adding 1 mL of amyl alcohol, the mixture was centrifuged at a speed of 1100 rpm for a duration of 15 min. The quantification of fat content was subsequently determined by observing the calibrated tube of the butyrometer. The quantitative values of protein, fat, ash, and moisture in the yoghurt were initially determined and combined to determine the total quantity of carbohydrates [13,14].

$$\text{Total carbohydrates } \% = 100 - (\text{moisture}\% + \text{protein}\% + \text{fat}\% + \text{ash}\%)$$

Physiochemical Tests

The percentage of total acidity was determined using the titration method, while the pH value was measured utilizing a pH meter (SD-300 pH, Dortmund City, Germany). The apparent viscosity of fortified set yoghurt was quantified at ambient temperature using a Brookfield digital viscometer (Middleboro, MA 02346, USA) [15]. The determination of susceptibility to syneresis (*STS*) involved the collection of whey from a 100 mL sample of yoghurt onto filter paper. The *STS* percentage was then calculated using the appropriate formula.

$$STS = 1 - [V1 - V2] \times 100$$

where $V1$ is the volume of whey collected and $V2$ is the volume of yoghurt [16].

Starter Bacteria Count

The quantification of starter bacteria viability for each individual can be ascertained through the utilization of the pour plate technique. *St. thermophilus* can be grown on M17 media at a temperature of 42 °C for a duration of 48 h under aerobic conditions. On the other hand, *Lb. acidophilus* and *B. bifidum* necessitate anaerobic conditions for growth. *Lb. acidophilus* should be cultured on MRS-sorbitol, while *B. bifidum* should be cultured on MRS-NNLP. Both should be incubated at a temperature of 37 °C for a period of 48 to 72 h [17].

2.3. Yoghurt Drying

In this experimental procedure, a precisely measured quantity of 50 g of yoghurt was uniformly distributed onto a glass dish that had been sterilized. The glass dish possessed dimensions of 50 cm in length, 10 cm in width, and a thickness of 0.5 cm. The dish was subsequently introduced into an air convection oven, where it was subjected to controlled temperatures of 40, 50, and 60 °C for 8–10 h, until the yoghurt reached a state of complete desiccation [18].

2.4. Reconstitution of Dried Yoghurt

The dried yoghurt was reconstituted in lukewarm (50 °C) water using a 1:6 powder-to-water ratio. After stirring, the mixture was allowed to cool to 50 °C for 5 min before being poured into cups and refrigerated to enable the reconstituted yoghurt to set. The chemical composition of dried yoghurt was investigated [19]. Furthermore, pH, total acidity %, viscosity, water-holding capacity (WHC), and hygroscopicity were measured at 0, 1, 2, and 3 month intervals while the dried yoghurt samples were stored in polyethylene bags in the refrigerator at a temperature of 7 ± 2 °C and a humidity of 30–50% [20,21]. The enumeration of the initial bacterial population in the dried yoghurt was conducted throughout the duration of its storage [22].

2.5. Statistical Analysis

Mean values and standard deviations were calculated as part of the statistical analysis. Using Genstat 12 microarray examples for Microsoft Windows 11, the data were then submitted to one-way analysis of variance (ANOVA) and unpaired least significant difference (L.S.D.). A p-value of less than 0.05 was considered statistically significant.

3. Results and Discussion

3.1. Bio-Yoghurt Properties

Table 1 shows the chemical components, physical properties, and microbiological features of yogurt within 24 h of production. Protein, carbohydrate, ash, moisture, and fat percentages were 5.17, 5.02, 1.10, 88.45, and 0.26, respectively, while the total solids percentage was 11.55%. Increase in percentages of yoghurt ingredientes compared to raw milk was surprising, and a convinced explanation is not available. As a result, the viscosity exhibited a notable increase to a value of 1645 cp. The pH levels exhibited a decline to 4.33, while the overall acidity experienced an elevation of 1.12%. This phenomenon can be attributed to the enzymatic transformation of lactose sugar into organic acids, specifically acetic and lactic acid, facilitated by the starter bacteria. The presence of elevated bacterial populations is apparent, as indicated by the high bacterial counts. Specifically, *St. thermophilus* was found to have a count of 8.86 log CFU/g, *Lb. acidophilus* had a count of 8.72 log CFU/g, and *B. bifidium* had a count of 8.71 log CFU/g. The predominance of *St. thermophilus* can be attributed to the optimal growth conditions provided by the incubation temperature of the yoghurt. These findings were consistent with prior research that suggests the development of a gelatinous matrix within yoghurt following the cooling process. Additionally, there was evidence of a decline in pH levels and a rise in overall acidity as a result of the utilization of lactose and its subsequent transformation into organic acids by lactic acid bacteria [23,24].

Table 1. Chemical, physical, and microbial properties of produced bio-yoghurt.

Tests		Value *
Chemical	Protein (N × 6.38) %	5.17 ± 0.13
	Carbohydrates (lactose)%	5.02 ± 0.09
	Ash (%)	1.10 ± 0.01
	Moisture (%)	88.45 ± 5.06
	Fat (%)	0.26 ± 0.00
Physical	pH	4.33 ± 0.11
	Total acidity (%)	1.12 ± 0.03
	Viscosity (cp)	1645 ± 35.19
	Syneresis (%)	29.14 ± 2.15
	Water-holding capacity (%)	55.79 ± 3.36
Microbial	*St. thermophilus* (log CFU/g)	8.86 ± 0.29
	Lb. acidophilus (log CFU/g)	8.72 ± 0.41
	B. bifidium (log CFU/g)	8.71 ± 0.25

* Note: mean (±SD) values (n = 3 replicates).

3.2. Dried Yoghurt Properties

Tables 2 and 3 present the chemical composition and physicochemical properties of dried yoghurt at temperatures of 40, 50, and 60 °C over a storage period of 3 months. The findings suggest that the application of heat treatment resulted in a substantial reduction in moisture content, thereby causing an increase in the proportion of other constituents. The protein and ash content values of the dried yoghurt produced at temperatures of 40 °C, 50 °C, and 60 °C exhibited a range of 37.51% to 39.59% and 6.37% to 6.40%, respectively. Upon examination of the findings from the present investigation, it was noted that the protein content exhibited an increase while the ash content diminished in comparison to the values documented by Kumar and Mishra [5]. Based on the report, it has been determined that skim milk yoghurt powder possesses a protein content ranging from 35% to 37%, along with an ash content ranging from 7.5% to 8.5%. The objective of this study was to attain a moisture content level of 5% in order to enhance the feasibility of long-term storage. This was accomplished by optimizing the process conditions, which encompassed the operating time and the application temperature for water removal. The lactose content, which is a type of carbohydrate, was determined to fall within the range of 48.61–50.16%. An empirical observation revealed a negative correlation between temperature and the proportion of carbohydrates in yoghurt during the drying process. In general, skim milk exhibits a fat content ranging from 0.1% to 0.5%. Subsequent to its transformation into yoghurt powder, the lipid content was determined to range between 1.33% and 1.43%. The observed rise in fat content can be ascribed to the decrease in moisture resulting from the process of dehydration. The findings of the current study closely align with those of a prior research endeavor, wherein it was observed that dried yoghurt derived from skim milk showcased a chemical composition comprising approximately 35–37% protein, 45–50% carbohydrates, and 7.5–8.5% ash content. Furthermore, the lipid composition of the yoghurt was determined to be 1.5%, while the water content was measured to be 5%.

Table 2. Chemical ingredients of dried yoghurt product at 40, 50, and 60 °C storage periods.

Chemical Ingredients	Treatments (°C)	Storage Periods (Months)			
		0	1	2	3
Protein (N × 6.38) %	40	37.51 ^{c} ± 2.13	37.58 ^{b} ± 2.63	37.70 ^{ab} ± 1.84	37.78 ^{ab} ± 2.31
	50	38.49 ^{b} ± 1.11	38.43 ^{b} ± 1.90	38.28 ^{a} ± 1.55	38.61 ^{a} ± 1.34
	60	39.28 ^{a} ± 1.18	39.41 ^{a} ± 1.43	39.46 ^{a} ± 1.31	39.59 ^{a} ± 1.01
Carbohydrates (lactose) %	40	50.16 ^{a} ± 2.95	50.11 ^{a} ± 3.15	50.09 ^{a} ± 3.11	50.07 ^{a} ± 2.97
	50	49.29 ^{a} ± 2.61	49.37 ^{a} ± 2.10	49.56 ^{a} ± 2.01	49.22 ^{a} ± 2.41
	60	48.68 ^{ab} ± 1.99	48.64 ^{ab} ± 2.39	48.66 ^{b} ± 2.19	48.61 ^{ab} ± 2.59
Ash (%)	40	6.37 ^{a} ± 0.12	6.38 ^{a} ± 0.31	6.38 ^{a} ± 0.22	6.40 ^{a} ± 0.19
	50	6.37 ^{a} ± 0.10	6.40 ^{a} ± 0.22	6.38 ^{a} ± 0.09	6.44 ^{a} ± 0.11
	60	6.55 ^{a} ± 0.19	6.50 ^{a} ± 0.81	6.44 ^{a} ± 0.41	6.40 ^{a} ± 0.21
Moisture (%)	40	4.55 ^{a} ± 0.06	4.52 ^{a} ± 0.10	4.42 ^{a} ± 0.11	4.33 ^{a} ± 0.09
	50	4.42 ^{a} ± 0.01	4.40 ^{a} ± 0.12	4.38 ^{a} ± 0.15	4.33 ^{a} ± 0.18
	60	4.16 ^{a} ± 0.02	4.12 ^{ba} ± 0.09	4.08 ^{a} ± 0.08	4.00 ^{a} ± 0.05
Fat (%)	40	1.41 ^{a} ± 0.01	1.41 ^{a} ± 0.02	1.41 ^{a} ± 0.01	1.42 ^{a} ± 0.01
	50	1.43 ^{a} ± 0.03	1.40 ^{a} ± 0.05	1.40 ^{a} ± 0.05	1.40 ^{a} ± 0.02
	60	1.33 ^{a} ± 0.04	1.33 ^{a} ± 0.06	1.36 ^{a} ± 0.01	1.40 ^{a} ± 0.01

Note: mean (±SD) values (n = 3 replicates) within a column with different lowercase letters are significantly different according to the least significant difference test ($p < 0.05$).

Table 3. Physical properties of dried and reconstituted dried yoghurt products during storage periods.

Physical Properties	Treatments (°C)	Storage Periods (Months)			
		0	1	2	3
pH	40	4.60 [a] ± 0.17	4.55 [a] ± 0.12	4.50 [a] ± 0.16	4.31 [a] ± 0.09
	50	4.32 [a] ± 0.14	4.30 [a] ± 0.11	4.29 [a] ± 0.10	4.25 [a] ± 0.13
	60	4.11 [b] ± 0.41	4.10 [b] ± 0.22	4.06 [b] ± 0.31	4.00 [a] ± 0.17
Total acidity (%)	40	1.35 [a] ± 0.02	1.39 [a] ± 0.05	1.40 [a] ± 0.03	1.41 [a] ± 0.08
	50	1.36 [a] ± 0.01	1.38 [a] ± 0.01	1.40 [a] ± 0.05	1.44 [a] ± 0.07
	60	1.36 [a] ± 0.01	1.37 [a] ± 0.08	1.40 [a] ± 0.01	1.41 [a] ± 0.02
Viscosity (cp)	40	600.00 [a] ± 15.31	550.00 [a] ± 12.61	510.00 [a] ± 32.00	450.00 [b] ± 44.15
	50	620.00 [a] ± 11.11	580.00 [a] ± 10.17	530.00 [a] ± 21.09	500.00 [a] ± 26.74
	60	550.00 [b] ± 19.28	525.00 [a] ± 10.73	510.00 [a] ± 17.71	500.00 [a] ± 21.19
WHC (%)	40	36.11 [a] ± 1.25	36.23 [a] ± 1.39	36.29 [b] ± 1.11	37.01 [b] ± 1.95
	50	37.00 [a] ± 1.09	37.23 [a] ± 1.13	37.50 [a] ± 1.34	37.73 [a] ± 1.35
	60	37.00 [a] ± 1.36	37.21 [a] ± 1.94	37.56 [a] ± 1.68	38.03 [a] ± 1.61
Hygroscopicity (%)	40	9.69 [a] ± 0.42	9.55 [a] ± 0.64	9.42 [a] ± 0.55	9.21 [a] ± 0.91
	50	9.55 [a] ± 0.16	9.50 [a] ± 0.27	9.40 [a] ± 0.31	9.16 [a] ± 0.63
	60	9.15 [b] ± 0.22	9.10 [b] ± 0.37	8.98 [b] ± 0.81	8.87 [b] ± 0.62

Note: mean (±SD) values (n = 3 replicates) within a column with different lowercase letters are significantly different according to the least significant difference test ($p < 0.05$).

The pH values and total acidity levels of the reconstituted dried yoghurt samples were determined and observed to fall within the ranges of 4.00–4.60 and 1.35–1.44%, respectively. The pH value and total acidity of the dried yoghurt product did not exhibit any significant changes due to variations in temperature and storage duration, as determined by statistical analysis ($p > 0.05$). The pH values deemed appropriate for the reconstitution of yoghurt powders were those exceeding 4.00, as pH values falling below this threshold were consistently rejected by consumers [25]. The permissible range of the total acidity ratio for yoghurts falls within the interval of 0.6% to 1.5%. Hence, the concentrations of lactic acid in the dried yoghurt specimens were quantified and determined to fall within the permissible thresholds for fluctuations in temperature and duration of storage, thereby establishing their viability for the manufacturing of dried yoghurts.

The results of the investigation revealed that the water-holding capacity (WHC) of the reconstituted dried yoghurt samples exhibited a range of values, specifically between 36.11% and 38.03%. Significantly, the treatment at 40 °C produced the lowest WHC, while the WHC exhibited an increase at lower temperatures. Following a three-month storage period, it was observed that the WHC of the reconstituted dried yoghurt remained unaltered when subjected to various drying temperatures (40, 50, and 60 °C). The observed disparity in rehydrated samples may be attributed to the observed increase in protein aggregates in the dried yoghurt samples produced at a temperature of 60 °C. The formation of substantial protein aggregates results in the creation of more robust gels, which exhibit enhanced WHC within the gel matrix. The reconstituted dried yoghurt demonstrated a notable reduction in WHC when compared to the fresh yoghurt [26].

The findings from the viscosity analysis performed on reconstituted dried yoghurt demonstrate a notable decrease in viscosity when compared to the original, unprocessed yoghurt sample. The viscosity measurement of reconstituted dried yoghurt varied between 500 and 700 cp. The results exhibited a significant influence on viscosity measurements at different drying temperatures, with higher temperatures leading to decreased viscosity values in reconstituted dried yoghurt samples. This observed phenomenon can be attributed to the consistent protein matrix that captures both lipid droplets and aqueous molecules. The structural integrity of this matrix becomes damaged during the process of desiccation, and its ability to fully recover upon rehydration is hindered due to the denaturation reactions that take place. The reconstitution process can be optimally achieved by employing a less stringent drying methodology. Moreover, similar results were observed in yoghurt samples that underwent dehydration using spray-drying techniques. The yoghurt product obtained from these powders demonstrated insufficient rheological properties due to their low apparent viscosity [27]. In a prior investigation, it was observed that the utilization of mechanical energy during the rehydration process, wherein water is combined, induces an irreversible deterioration of the gel network structure found in yoghurts reconstituted from dried powders [28]. Yoghurt samples exhibiting increased viscosity values are deemed unsuitable for the production of reconstituted yoghurt. On the contrary, these powdered substances may be more appropriate for utilization in the formulation of beverages like ayran, kumis, and kefir, which demonstrate comparatively lower measurements of viscosity in comparison to yoghurt [29].

The hygroscopic phenomenon pertains to the ability of a food substance to attract and retain water molecules from its immediate surroundings via absorption or adsorption, typically occurring at standard or ambient temperature. When water molecules are distributed among the molecules of a substance, adsorbing agents have the potential to undergo physical modifications, including changes in volume, boiling point, viscosity, or other physical characteristics [30]. Based on the quantitative information provided in Tables 2 and 3, it was observed that the dried yoghurt samples demonstrated a diminished propensity for absorbing moisture, as indicated by the hygroscopicity values ranging from 9.69% to 8.87%. The result of this study aligns with the outcomes documented by previous studies [31,32] on the production of yoghurt powder through the process of spray drying. It is important to mention that lactose, a crucial constituent in yoghurt, exhibits a glass transition temperature of 101 °C [33]. Furthermore, in previous studies, yoghurt drying was performed using four different methods: air drying, vacuum drying, freeze drying, and microwave vacuum drying. After analysis using scanning electron microscopy and X-ray diffraction patterns, no crystallization of lactose was seen to have occurred in the dried product [34]. This implies that the drying temperature utilized in this investigation was maintained below this critical value. Therefore, it can be inferred that the sugars present in the samples acquired through the process of oven drying and other methodologies exhibit comparable characteristics. Hence, similar levels of hygroscopicity were observed under varying drying temperatures. The findings suggest that the application of elevated temperatures during the drying procedure led to a decrease in the hygroscopicity percentage. This phenomenon can be ascribed to modifications in the bonding of the gelatinous matrix between saccharides and proteins, coupled with a decrease in the proportion of lactose at higher drying temperatures.

3.3. Bacteria Starter Count

The log CFU/g of *St. thermophilus*, *La acidophilus*, and *B. bifidum* in dried yoghurt was measured after subjecting samples to drying in an air oven at temperatures of 40, 50, and 60 °C. The samples were then stored for different durations of time (0, 1, 2, and 3 months). The specific values can be found in Figure 1. The empirical evidence suggests that the population of viable starter bacteria experienced a decline as a result of the elevated temperatures employed during the drying procedure. *B. bifidum* exhibited a greater degree of negative impact compared to *St. thermophilus* and *Lb. acidophilus*, likely due to its mesophilic bacterial nature in contrast to the thermotolerant characteristics of the latter two species. The bacterial populations of *St. thermophilus*, *Lb. acidophilus*, and *B. bifidum* were measured subsequent to drying at a temperature of 40 °C. On the initial day of storage, the bacterial counts were recorded as 7.22, 7.15, and 6.96 log CFU/g, respectively. Following a storage period of 90 days, the bacterial counts exhibited a decline, resulting in values of 6.86, 6.75, and 6.66 log CFU/g, respectively. Subjecting the samples to elevated temperatures of

50 °C and 60 °C led to a reduction in bacterial populations. Precisely, the measurement of bacterial populations for *St. thermophilus* yielded values of 6.45 and 5.28 log CFU/g, respectively. The recorded counts for *Lb. acidophilus* were 6.99 and 5.13 log CFU/g, respectively. The counts of *B. bifidum* were 6.50 and 4.81 log CFU/g, respectively. The observed counts exhibited a consistent downward trend as the duration of storage increased. The findings of this investigation were consistent with a prior research endeavor, wherein the quantities of *Lb. acidophilus* and *B. bifidum*, two types of bacteria commonly found in starter yoghurt, were determined to be 4.65 log CFU/g after employing the spray-drying method for the dehydration of yoghurt [35].

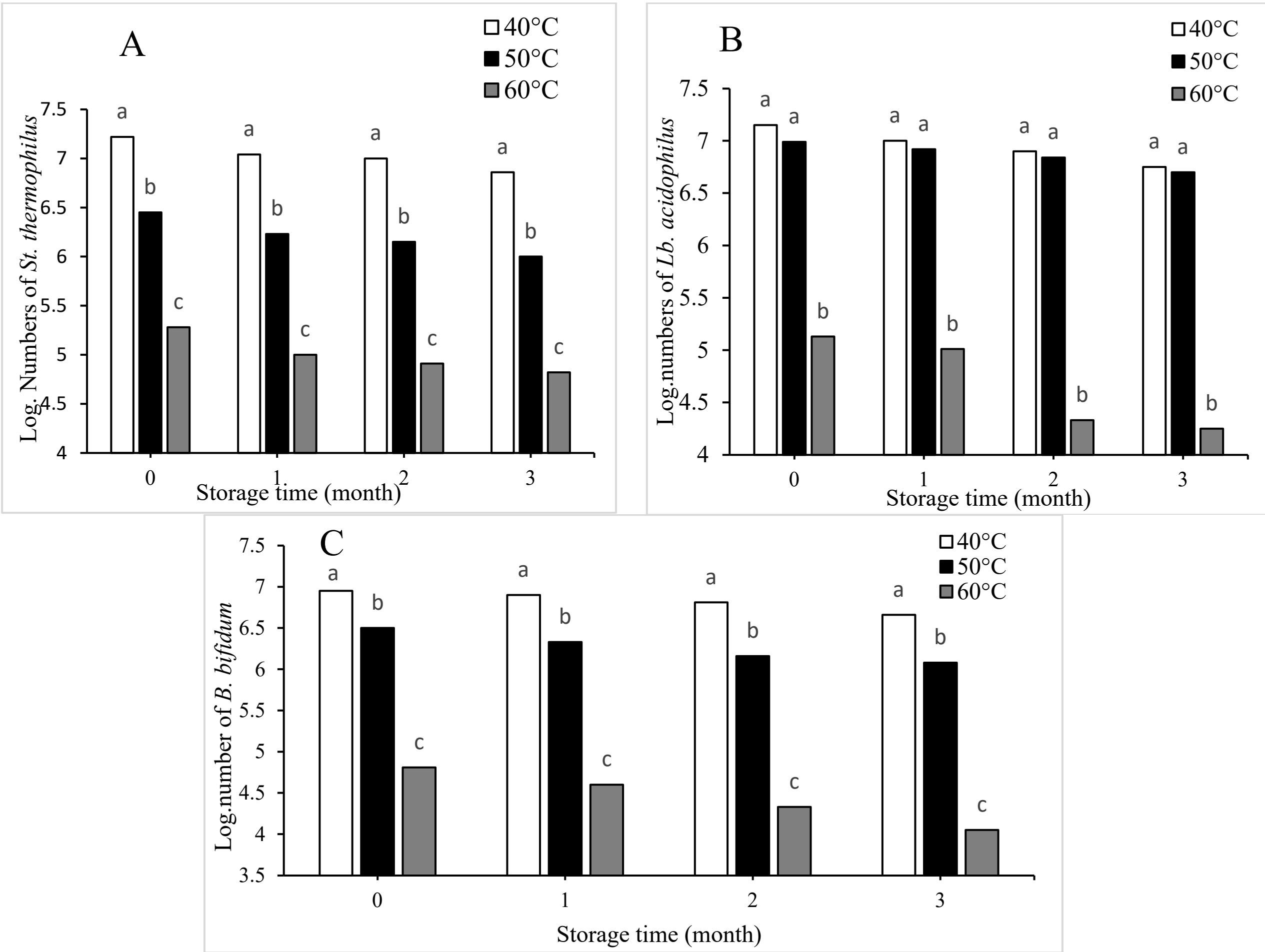

Figure 1. Starter bacteria count of dried yoghurt samples during storage periods (3 moths): (**A**) *St. thermophilus* count, (**B**) *Lb. acidophilus* count, (**C**) *B. bifidum* count. a–c Different small letters of starter bacteria numbers were significantly different ($p < 0.05$).

The ability of yoghurt starter cultures to retain a substantial population of bacteria following the drying process is ascribed to the presence of a protective matrix composed of total solids that encompass the bacterial cells. The protective layer serves to mitigate the detrimental effects on the cellular membranes caused by desiccation, while also facilitating an encapsulation procedure that effectively maintains the bacteria's viability [36]. The most suitable quality parameter for assessing process-induced damage and optimizing process conditions in dried yoghurt is a count of viable yoghurt bacteria [27]. The utilization of air oven drying at a temperature of 40 °C serves as an alternative technique for the production of yoghurt powder, resulting in improved physical characteristics. The utilization of prebiotics or thermotolerant strains of yoghurt bacteria in the process of dried yoghurt production can be considered as a viable approach to maintain the survival and functionality of bacteria during the drying process at temperatures exceeding 40 °C. Prebiotics bind to protein to form a network that protects the lactic acid bacteria contained inside it from the effects of drying processes [37]. However, additional research is necessary to investigate the feasibility of microorganisms that have biological and nutritional importance, such as the bacteria found in yoghurt, in powders that are produced through the process of air oven drying [38].

4. Conclusions

The results show the possibility of using an air oven (40–60 °C) to dry yoghurt containing probiotic bacteria, and the dried product had satisfactory physical properties and significant solids content, although viscosity measurements showed a decrease. Furthermore, using air oven drying reduced the number of bacteria in the dried yogurt powder samples. At higher drying temperatures (60 °C), the extent of the reduction was more pronounced. The dried yoghurt product effectively maintained the viability of many probiotic bacteria for three months, making the product easier to transport and handle. This is in contrast to freshly made yoghurt, which has a relatively limited shelf life.

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References

1. Kok, C.R.; Hutkins, R. Yogurt and Other Fermented Foods as Sources of Health-Promoting Bacteria. *Nutr. Rev.* **2018**, *76*, 4–15. [CrossRef] [PubMed]
2. Hadjimbei, E.; Botsaris, G.; Chrysostomou, S. Beneficial Effects of Yoghurts and Probiotic Fermented Milks and Their Functional Food Potential. *Foods* **2022**, *11*, 2691. [CrossRef] [PubMed]
3. Al-Kadamany, E.; Khattar, M.; Haddad, T.; Toufeili, I. Estimation of Shelf-Life of Concentrated Yogurt by Monitoring Selected Microbiological and Physicochemical Changes during Storage. *LWT* **2003**, *36*, 407–414. [CrossRef]
4. Joel, N.; James, S.; Blessing, O.O. Development and Comparative Evaluation of Storage Changes in Probiotic Soy-Yoghurt. *J. Microbiol. Biotechnol. Food Sci.* **2019**, *9*, 298–301. [CrossRef]
5. Kumar, P.; Mishra, H.N. Yoghurt Powder—A Review of Process Technology, Storage and Utilization. *Food Bioprod. Process.* **2004**, *82*, 133–142. [CrossRef]
6. Krasaekoopt, W.; Bhatia, S. Production of Yogurt Powder Using Foam-Mat Drying. *AU J. Technol.* **2012**, *15*, 166–171.
7. Mattila-Sandholm, T.; Myllärinen, P.; Crittenden, R.; Mogensen, G.; Fond, R.; Saarela, M. Technological Challenges for Future Probiotic Foods. *Int. Dairy J.* **2002**, *12*, 173–182. [CrossRef]
8. Soysona Ar, Ö.; Ocak, E. Storage of Yoghurt Powder Obtained by Different Drying Methods and Its Use in Reconstituted Ayran Production. *Yuz. Yil Univ. J. Agric. Sci.* **2022**, *32*, 42–56. [CrossRef]
9. Al-Sahlany, S.T.G.; Khassaf, W.H.; Niamah, A.K.; Al-Manhel, A.J. Date Juice Addition to Bio-Yogurt: The Effects on Physicochemical and Microbiological Properties during Storage, as Well as Blood Parameters in Vivo. *J. Saudi Soc. Agric. Sci.* **2023**, *22*, 71–77. [CrossRef]
10. Niamah, A.K. Physicochemical and Microbial Characteristics of Yogurt with Added *Saccharomyces boulardii*. *Curr. Res. Nutr. Food Sci.* **2017**, *5*, 300–307. [CrossRef]
11. Niamah, A.K.; Al-fekaiki, D.F.; Thyab Gddoa Al-Sahlany, S.; Verma, D.K.; Patel, A.R.; Singh, S. Investigating the Effect of Addition of Probiotic Microorganisms (Bacteria or Yeast) to Yoghurt on the Viability and Volatile Aromatic Profiles. *J. Food Meas. Charact.* **2023**, *17*, 5463–5473. [CrossRef]

12. Nagaoka, S. Yogurt Production. In *Methods in Molecular Biology*; Humana Press Inc.: Totowa, NJ, USA, 2019; Volume 1887, pp. 45–54.
13. Horwitz, W. *Official Methods of Analysis*; Association of Official Analytical Chemists: Washington, DC, USA, 1975; Volume 222.
14. AOAC. *International A: Official Methods of Analysis of the AOAC International*, 17th ed.; The Association: Arlington County, VA, USA, 2000.
15. Bensoltane, A.; Fadela, C.; Abderrahim, C.; Ahmed, B. Physico-chemical and rheological properties of yoghurt manufactured with ewe's milk and skim milk. *Afr. J. Biotechnol.* **2009**, *8*, 1938.
16. Niamah, A.K.; Thyab, S.; Al-Sahlany, G.; Al-Manhel, A.J. Gum Arabic Uses as Prebiotic in Yogurt Production and Study Effects on Physical, Chemical Properties and Survivability of Probiotic Bacteria During Cold Storage. *World Appl. Sci. J.* **2016**, *34*, 1190–1196. [CrossRef]
17. Niamah, A.K. Ultrasound Treatment (Low Frequency) Effects on Probiotic Bacteria Growth in Fermented Milk. *Future Food J. Food Agric. Soc.* **2019**, *7*, 103. [CrossRef]
18. Tontul, İ.; Ergin, F.; Eroğlu, E.; Küçükçetin, A.; Topuz, A. Physical and Microbiological Properties of Yoghurt Powder Produced by Refractance Window Drying. *Int. Dairy J.* **2018**, *85*, 169–176. [CrossRef]
19. Nielsen, S. Suzanne. In *Food Analysis*; Aspen Publishers: Boston, MA, USA, 1998; ISBN 083421203X.
20. Özaslan, M.S.; Demir, Y.; Aksoy, M.; Küfrevioğlu, Ö.I.; Beydemir, Ş. Inhibition Effects of Pesticides on Glutathione-S-Transferase Enzyme Activity of Van Lake Fish Liver. *J. Biochem. Mol. Toxicol.* **2018**, *32*, e22196. [CrossRef] [PubMed]
21. Chetachukwu, A.S.; Thongraung, C.; Yupanqui, C.T. Development of Reduced-Fat Coconut Yoghurt: Physicochemical, Rheological, Microstructural and Sensory Properties. *Int. J. Dairy Technol.* **2019**, *72*, 524–535. [CrossRef]
22. Yosry Abdel Halim, E.; El-Essawy, H.; Abdel Nasser Awad, A.; El-Kutry, M.S.; Ibrahim Ahmed, L. Estimating the Microbial Safety and Sensory Characteristics of Some Imported Dairy Products Retailed in the Egyptian Markets. *Adv. Anim. Vet. Sci.* **2022**, *10*, 488–499. [CrossRef]
23. Meybodi, N.M.; Mortazavian, A.M.; Arab, M.; Nematollahi, A. Probiotic Viability in Yoghurt: A Review of Influential Factors. *Int. Dairy J.* **2020**, *109*, 104793. [CrossRef]
24. Lopes, R.P.; Mota, M.J.; Sousa, S.; Gomes, A.M.; Delgadillo, I.; Saraiva, J.A. Combined Effect of Pressure and Temperature for Yogurt Production. *Food Res. Int.* **2019**, *122*, 222–229. [CrossRef]
25. Saatloo, N.V.; Mehdizadeh, T.; Aliakbarlu, J.; Tahmasebi, R. Physicochemical, Sensory and Microbiological Characteristics of Coriander Seed Powder Yogurt. *AMB Express* **2023**, *13*, 66. [CrossRef] [PubMed]
26. Yüksel, A.N. Development of Yoghurt Powder Using Microwave-Assisted Foam-Mat Drying. *J. Food Sci. Technol.* **2021**, *58*, 2834–2841. [CrossRef] [PubMed]
27. Koc, B.; Yilmazer, M.S.; Balkir, P.; Ertekin, F.K. Spray Drying of Yogurt: Optimization of Process Conditions for Improving Viability and Other Quality Attributes. *Dry. Technol.* **2010**, *28*, 495–507. [CrossRef]
28. Andronoiu, D.-G.; Nistor, O.-V.; Mocanu, G.-D.; Barbu, V.; Botez, E.; Petroiu, M. Quality characteristics of yoghurt powder obtained by hybrid drying methods. *J. Hyg. Eng. Des.* **2019**, *29*, 15–20.
29. Santos, G.D.; Nunes, T.P.; Silva, M.A.A.P.; Rosenthal, A.; Pagani, A.A.C. Development and Acceptance of Freeze-Dried Yogurt "Powder Yogurt". *Int. Food Res. J.* **2018**, *25*, 1159–1165.
30. Tereshchenko, A.G. Dynamic Method for the Determination of Hygroscopicity of Water-Soluble Solids. *J Solut. Chem.* **2020**, *49*, 1029–1051. [CrossRef]
31. Öztürk, H.İ. The Effect of Different Lyophilisation Pressures on the Microbiological Stability, Physicochemical, Microstructural, and Sensorial Properties of Yoghurt Powders. *Int. Dairy J.* **2022**, *129*, 105347. [CrossRef]
32. Tornuk, F.; Ozturk, I.; Karaman, S.; Sagdic, O.; Yetim, H. Rheological and Some Physicochemical Properties of Probiotic Boza Beverage Fermented with Lactobacillus Casei Shirota: Application of Principal Component Analysis for the Characterisation. *Qual. Assur. Saf. Crops Foods* **2014**, *6*, 237–247. [CrossRef]
33. Roos, Y.H. Importance of glass transition and water activity to spray drying and stability of dairy powders. *Le Lait* **2002**, *82*, 475–484. [CrossRef]
34. Jaya, S. Microstructure analysis of dried yogurt: Effect of different drying methods. *Int. J. Food Prop.* **2009**, *12*, 469–481. [CrossRef]
35. Wirjantoro, T.I.; Phianmongkhol, A. The viability of lactic acid bacteria and *Bifidobacterium bifidum* in yoghurt powder during storage. *J. Nat. Sci.* **2009**, *8*, 95–104.
36. Niamah, A.K.; Gddoa Al-Sahlany, S.T.; Ibrahim, S.A.; Verma, D.K.; Thakur, M.; Singh, S.; Patel, A.R.; Aguilar, C.N.; Utama, G.L. Electro-Hydrodynamic Processing for Encapsulation of Probiotics: A Review on Recent Trends, Technological Development, Challenges and Future Prospect. *Food Biosci.* **2021**, *44*, 101458. [CrossRef]
37. Kiepś, J.; Dembczyński, R. Current Trends in the Production of Probiotic Formulations. *Foods* **2022**, *11*, 2330. [CrossRef] [PubMed]
38. El-Sayed, H.S.; Salama, H.H.; Edris, A.E. Survival of Lactobacillus Helveticus CNRZ32 in Spray Dried Functional Yogurt Powder during Processing and Storage. *J. Saudi Soc. Agric. Sci.* **2020**, *19*, 461–467. [CrossRef]