Scientific Research Publishing

Food and Nutrition Sciences, 2022, 13, 404-423
https://www.scirp.org/journal/fns
ISSN Online: 2157-9458
ISSN Print: 2157-944X

The Impact of Sweet Potato Flour Supplementation on Functional and Sensorial Properties of Yoghurt

Aisha El-Attar[1*], Nour El-Hoda Ahmed[1], Morsi El-Soda[1], Silvia M. Zaki[2]

[1]Laboratory of Microbial Biochemistry of Dairy Microorganisms, Department of Dairy Science and Technology, Faculty of Agriculture, Alexandria University, Alexandria, Egypt
[2]Department of Dairy Science and Technology, Faculty of Agriculture, Alexandria University, Alexandria, Egypt
Email: *elattar2001@hotmail.com, aisha.abdelmaksoud@alexu.edu.eg

How to cite this paper: El-Attar, A., Ahmed, N.E.-H., El-Soda, M. and Zaki, S.M. (2022) The Impact of Sweet Potato Flour Supplementation on Functional and Sensorial Properties of Yoghurt. *Food and Nutrition Sciences*, **13**, 404-423.
https://doi.org/10.4236/fns.2022.134030

Received: March 13, 2022
Accepted: April 21, 2022
Published: April 24, 2022

Abstract

Sweet potatoes have become a research focus in recent years, due to their particular nutritional and functional qualities. Considering yoghurt is one of the most popular dairy products, sweet potato supplementation will play a significant impact on the produced yoghurt texture it will also add attractive orange colour to the final product. The article focused on the replacement of the stabilizers used in the manufacture of yoghurt with sweet potato flour dehydrated in a lab (SPFL) due to its functional features and a less expensive alternative and the improvement of yoghurt colour due to the presence of anthocyanin pigment. In order to reach these goals, experimental yoghurt was fortified with 0, 0.5, 1, 2, and 4 g SPFL/100g cow milk (%) and stored at 4˚C for 14 days. The obtained data were then compared with commercial yoghurt samples (CS1, CS2, CS3, and CS4). Sensory evaluation revealed that the 2% SPFL, CS1, and CS3 obtained higher scores than the other treatments. The fat content of the yoghurts was identical whereas, the other physicochemical parameters and water holding capacity (WHC %) levels varied. SPFL supplementation had a significant impact on the rheological properties of yoghurt production, allowing sweet potato flour to replace the industrial stabiliser. Scanning Electron Micrograph (SEM) of yoghurt enriched with SPFL revealed denser and smaller gaps, as well as the presence of sweet potato globules embedded in and attached to the gel matrix. The results obtained in the present research imply that sweet potatoes can be used to produce a kind of cohesive and gummy yoghurt that can be used instead of industrial stabilizers.

Keywords

Sweet Potato Yoghurt, Sensorial Evaluation, Physicochemical, Rheological Properties and Microstructural Properties

1. Introduction

Recently, the consumer's awareness of food ingredients has considerably risen (Mousavi *et al.* 2019) [1]. As a result of nutritionists' consideration that dairy products are beneficial to human health, due to their great digestibility and nutritional value (García-Pérez *et al.* 2005; Sadeghi, 2016) [2] [3]. Yoghurt is one of the most widely available cultured dairy products in developed countries, where its admiration stems from its flavour and diversity (Okoye and Obi 2013) [4]. Its manufacturing is based on the coagulation of pasteurized milk through the act of *Lactobacillus bulgaricus* and *Streptococcus thermophilus* and/or other suitable lactic acid bacteria (LAB). Yoghurt has long been thought to provide health benefits, therefore expanding the product range to other types of health-promoting products is quite natural for the dairy sector. In the yoghurt manufacture, foodstuffs can be added to achieve optimal consistency and syneresis stability, which is of fundamental significance to the dairy industry. As the main problem faced by the yoghurt industry and maintenance is stability and optimum consistency. Stabilizers are added to yoghurt to improve texture, mouthfeel, and appearance, as well as to reduce syneresis (El-Sayed *et al.* 2002) [5]. Functional dairy products are becoming more widely available in the daily-dose style, which has grown in popularity in recent years (Ortiz *et al.* 2017) [6]. Sweet potato (*Ipomoea batatas*) is one of the ingredients that can be added to the production of yogurt. It is a root crop cultivated extensively in the tropical and subtropical zones and belongs to the Convolvulaceae family. The sweet potato is a type of root vegetable, which ranks the fifth most important food crop in the world after corn, wheat, rice, and potato (FAOSTAT, 2016) [7]. In comparison to other major staple food crops, sweet potatoes have wide production geography, are adaptable to marginal conditions, have a short production cycle, have a high nutritional value, and have sensory versatility in terms of flesh colours, flavour, and texture. Sweet potatoes are rich in B-carotene, anthocyanin, total phenolic compounds, dietary fibre, ascorbic acid, folic acid, and minerals (Mu and Singh 2019) [8]. About 80% - 90% of sweet potato dry matter is made up of carbohydrates consisting mainly of starch. Sweet potatoes generally have a sweet taste but their natural sugars are delivered slowly into the bloodstream, indicating a low glycemic index. Therefore, sweet potato has a lot of potentials to contribute to human diets around the world. However, global trends in sweet potato production and consumption do not support this vital vegetable's position. Although the cultivation of sweet potatoes is widespread around the world, production is not evenly distributed around the world. China is the world's largest producer of sweet potatoes, followed by Africa. Egypt is the fifth-largest exporter of SP, accounting for 6.8% of total exports in 2020. While, it was graded 24^{th} in the globe in terms of production, with 0.49% of total production in 2019 (https://www.tridge.com/intelligences/sweet-potato/EG).

The situation can be attributable to the lack of sweet potato processing technologies, as well as the growing consumer demand for suitable products. Sweet potato, moreover is a critical food security crop that feeds millions of people in the developing world. The crop is extremely popular among Egyptians and generates more biomass and nutrients per hectare than any other food crop on the planet. As they consumed them as grilled roots and sometimes fried as chips.

Keeping in view all the benefits of SP as technological, health, and economic benefits, the present study was planned to use sweet potato flour (SPF) to improve the functional properties of cow set yoghurt. This supplementation substitutes for adding thickener agents. The orange colour of sweet potatoes shows the amount of anthocyanin pigment content that is very useful as an alternative synthetic food colour. So, orange sweet potato can improve the resulting yoghurt colour. As the produced yoghurt may help to improve consumer nutrition of root crops in Egypt and also ensure national security.

Considering all of SP's benefits, including technological, health, and economic benefits, the purpose of this research was to improve the functional properties of cow's milk set yoghurt using sweet potato flour dehydrated in the laboratory (SPFL). The yoghurt thickening agents are replaced by this enrichment. Furthermore, the orange colour of sweet potatoes is related to the presence of anthocyanin pigment, which can be utilized to replace synthetic colorants. As a result, the SPFL-enriched yoghurt may help to improve consumer nutrition for root crops and also safeguard national security.

2. Materials and Methods

2.1. Preparation of Sweet Potato Flour Dehydrated in the Laboratory (SPFL)

Sweet potato roots were rinsed in tap water (**Figure 1(a)**), manually peeled (**Figure 1(b)**), thinly cut into a 2 mm thickness (**Figure 1(c)**), cooked in water at 90˚C - 95˚C for 5 minutes (**Figure 1(d)**) and mashed them (**Figure 1(e)**). Then spread them out on a dehydrator and dry at 50˚C overnight (**Figure 1(f)**). After that, ran them through a blender to crush and sieve them through an 80-mesh sieve to produce a kind of uniform-size flour (**Figure 1(g)**). The produced flour was stored in an airtight container (**Figure 1(h)**) at −20˚C till using them.

2.2. Yoghurt Samples

2.2.1. Yoghurt Enriched with SPFL

Different percentages (control, 0.5, 1, 2, and 4 g/100g milk, %) of SPFL were added to whole cow milk (delivered from the Faculty of Agriculture and Alexandria University) as different treatments. Whole cow milk with added SPFL was pasteurized at 95˚C for 10 min then warmed in a water bath to approximately 42˚C, inoculated with (3%) commercial yoghurt culture Yoflex-L903 (The thermophilic lactic culture type yoghurt, CHR-HANSEN, Denmark). All samples were poured into 30mL bottles, and incubated at 42˚C. The fermentation was terminated at pH 4.7 ± 0.1 and the samples were stored at 4˚C for later tests (0, 7, and 14 days).

Figure 1. Preparation of sweet potato flour dehydrated in the laboratory (SPFL). (a) Rinsed sweet potato; (b) Peeled sweet potato; (c) Thinly cut sweet potato; (d) Cooked sweet potato; (e) Mashed sweet potato; (f) Spread SP on dehydrator; (g) Crushed SP on blender; (h) SP flour stored in air tight container.

2.2.2. Commercial Yoghurt

From the grocery, four different commercial yoghurt brands (CS1, CS2, CS3, and CS4) were obtained (Table 1). They were chosen based on the highest sales values.

2.3. Yoghurt Samples Analysis

2.3.1. Sensorial Evaluation

The final products, which had been held at 4˚C, were allowed to rest for 10 minutes at room temperature (25˚C) before being evaluated. A Hedonic scale (ISO and IDF 2009) [9] was used to assess the samples. The organoleptic properties of the studied yoghurts were examined, including colour, taste, smell, texture, appearance, and overall acceptability. The sensory evaluation was based on a scale with extremes ranging from good (scoring = 5 or 10 or 20) to very poor (score = 0). Fifteen panelists from the Faculty of agriculture at Alexandria University (staff members, undergrads, and graduates) performed sensory evaluations on the tested yoghurt samples with various concentrations of SPFL, as well as commercial samples. In addition, the panelists were asked to list any flavour defects.

2.3.2. Physicochemical Analysis

Yoghurt samples were analysed for moisture using the moisture analyser

Table 1. Different nutritional values of tested commercial yoghurt samples.

Commercial samples	Parameters					
	Energy (K·Cal/100g)	Protein (g/100g)	Fat (g/100g)	Carbohydrate (g/100)	Calcium (mg/100g)	Stabilizers and emulsifiers
CS1	66.17	3.07	2.87	6.7	74.05	E440, E471, E1422
CS2	64.76	3.57	3.10	5.04	130	E440
CS3	68	4.03	3.13	6.18	119	E440, E471, E1422
CS4	68	3.50	3.50	5.3	125	Natural stabilizers

(Mettler Toledo model HR73), total protein by the Kjeldahl method, (AOAC, 2010) [10]. The pH of yoghurt samples was measured by softening 20 g of yoghurt in 20 ml of deionized water using a glass electrode (Criston, Basic 20). The fat was estimated by the Gerber method, (AOAC, 2010) [10]. A high-performance colour measurement spectrophotometer (UltraScan®VIS Spectrophotometer, Hunter Associates Laboratory Inc., Va, USA) was used to analyse the samples' colours. The instrument was first standardized using a white tile (top of the scale) and a black tile (bottom of the scale). A yoghurt sample was inserted in the specimen port; and the colour's tri-stimulus values, namely L*, a*, and b*, were measured, as follows: L: value denotes darkness from black (0) to white (100), a: value represents colour ranging from red (+) to green (−) and b: value represents yellow (+) to blue (−) as defined by Seçkin and Baladura (2012) [11]. Using a digital Rotary Viscometers MYR, the apparent viscosity of the sample yoghurt was assessed at a constant temperature of 20˚C (VR 3000-Model L, Viscotech Hispania, S.L., El Venrell, Spain). A clean, dry glass beaker with a 120 ml capacity was used to hold the yoghurt sample. The spindle was inserted and centred in the sample until the fluid level reached the spindle shaft's immersion groove. After 30 seconds at a speed of 12 rpm, the measurement was always performed with the rotating spindle L3. The viscometer's digital output was used to obtain a reading of apparent viscosity in mPas (Nilsson *et al.* 2006) [12]. The centrifugation method described by Saffon *et al.* (2013) [13] was used to estimate the water holding capacity (WHC %) of yoghurt samples. It determines the amount of water absorbed in the protein structure. It was expressed as percent pellet weight over the original yoghurt weight (about 20 gm). The incubated yoghurt in the sterile centrifuge tubes was centrifuged at 10˚C at 13500 × g for 30 min (Marathon 21,000 R, Fischer Scientific). The supernatant fluid was drained for 20 min by inverting tubes at 24˚C ± 1˚C (room temperature). Water holding capacity was estimated according to Equation (1) and expressed in a percent:

$$\%\text{WHC} = \frac{\text{drained tube weight}(\text{gm}) - \text{empty tube weight}(\text{gm})}{\text{initial yogurt weight}(\text{gm})} \times 100 \quad (1)$$

2.3.3. Texture Profile Analysis

A texture analyser (TA1000, Lab Pro (FTC TMS-Pro), USA) was used to determine textural qualities. Yogurt samples were measured in cups (30 × 30 cm) and left at room temperature for at least 1 hour before being tested. A two-bite penetration test was done with a 1 mm/sec crosshead speed and a 10 mm penetration distance. In triplicate, hardness, adhesiveness, cohesiveness, springiness, and gumminess were evaluated. (Bourne 2002 and Szczesniak 1963) [14] [15].

2.3.4. Microstructure

The microstructure of yoghurt samples was studied by scanning electron microscope SEM Jeol model JXA-840A; (Japan), electron probe micro analyser using a magnification of 500× and 2000×, after one day of cold storage at 4˚C ± 1.0˚C. For at least 1 h, samples were fixed in 2.5% glutaraldehyde in cacodylate buffer (pH 7.2). After three rinses in cacodylate buffer, samples were postfixed for one hour in a 1% buffered osmium tetroxide. The fixed samples were dehydrated using a graded alcohol series (20%, 40%, 60%, 70%, and 90%) culminating with three changes of 100% alcohol, and then the critical point was dried from liquid CO2. At least three dried samples of each yoghurt were fragmented, mounted on aluminum cubs, and coated with gold in a K550X sputter coater (England) as described by Puvanenthiran *et al.* (2002) [16].

2.3.5. Statistical Analysis

All experiments were performed in triplicate, each value thus representing the mean of three measurements. So, all data were expressed as mean values ± SD. Statistical analyses were performed via Statistical Package for Social Science (SPSS Version 20). Statistical analyses were achieved using one-way analyses of variance (ANOVA). Differences between means were considered significant at 95% ($p < 0.05$) confidence level.

3. Results and Discussion

3.1. Sensorial Evaluation

Sensory evaluation helps in the definition of product qualities that are observable in terms of customer acceptability. To evaluate the sensory quality of the final product, sensory aspects such as body & texture, flavour, appearance, and overall acceptability were assessed (**Table 2**). Sweet potato flour concentrations have a substantial impact on the sensory attributes of different types of yoghurt samples. The results revealed that both T2 and commercial yoghurt samples (CS1 and CS3) scored highly for body & texture, appearance, and overall acceptance. As, T2 had the highest overall acceptability scores (18.08, 17.67, and 18.50) at zero, 7, and 14 days of storage, respectively when compared with the treated

Table 2. Sensorial evaluation average of yoghurt enriched with different percentages of sweet potato (0%, 0.5%, 1%, 2% and 4%) and commercial yoghurt samples at zero 7 and 14 days of storage at 4˚C.

	Storage (days)	Treatment					Commercial samples			
		C	T0.5	T1	T2	T4	CS1	CS2	CS3	CS4
Body and texture (5)	Zero	4.67 ± 0.52	4.33 ± 0.52	4.42 ± 0.80	4.83 ± 0.41	3.92 ± 0.92	4.58 ± 0.49	4.00 ± 1.26	4.83 ± 0.26	3.83 ± 1.47
	7	4.00 ± 0.63	4.00 ± 0.55	4.50 ± 0.45	4.83 ± 0.41	4.17 ± 0.98	4.25 ± 0.94	4.08 ± 1.56	4.83 ± 0.26	4.42 ± 0.80
	14	4.42 ± 0.49	4.33 ± 0.41	4.58 ± 0.38	4.83 ± 0.26	4.17 ± 0.68	4.75 ± 0.42	3.83 ± 1.17	4.83 ± 0.41	4.00 ± 0.89
Flavor (10)	Zero	8.75 ± 0.88	8.00 ± 0.63	8.83 ± 1.13	8.92 ± 0.80	7.83 ± 1.33	9.00 ± 0.89	7.17 ± 1.47	9.25 ± 1.60	7.25 ± 1.29
	7	7.58 ± 0.92	7.33 ± 0.61	8.50 ± 0.77	9.00 ± 1.10	8.50 ± 1.05	9.08 ± 0.58	7.08 ± 1.63	9.17 ± 0.75	7.58 ± 1.07
	14	8.50 ± 1.05	8.25 ± 0.69	8.67 ± 0.88	9.17 ± 0.68	8.92 ± 0.86	8.92 ± 1.02	6.83 ± 1.47	9.08 ± 0.66	7.42 ± 0.49
Appearance (5)	Zero	4.50 ± 0.55	4.17 ± 0.41	4.50 ± 0.63	4.50 ± 0.63	3.75 ± 0.42	4.50 ± 0.45	4.00 ± 0.89	4.75 ± 0.42	4.08 ± 1.02
	7	3.50 ± 0.45	3.67 ± 0.41	4.75 ± 0.42	4.75 ± 0.27	4.17 ± 0.82	4.25 ± 0.94	4.17 ± 0.82	4.50 ± 0.77	4.33 ± 0.52
	14	4.67 ± 0.52	4.42 ± 0.38	4.50 ± 0.77	4.67 ± 0.41	4.50 ± 0.55	4.83 ± 0.41	4.00 ± 0.89	4.83 ± 0.41	4.33 ± 0.52
Overall acceptance (20)	Zero	17.92 ± 1.56	16.50 ± 1.05	17.75 ± 2.21	18.25 ± 1.51	15.50 ± 1.90	18.08 ± 1.36	15.1 ± 2.64	18.83 ± 1.57	15.17 ± 2.34
	7	15.08 ± 1.53	15.00 ± 0.55	17.75 ± 1.25	18.58 ± 1.59	16.83 ± 2.73	17.67 ± 2.36	15.7 ± 3.11	18.58 ± 1.32	16.17 ± 1.17
	14	17.58 ± 1.91	17.00 ± 1.05	17.67 ± 1.97	18.67 ± 0.82	17.58 ± 1.91	18.50 ± 1.48	14.6 ± 3.01	18.7 ± 1.41	15.75 ± 1.54

C: yoghurt without sweet potato; T0.5: yoghurt fortified with 0.5% SPFL; T1: yoghurt fortified with 1% SPFL; T2: yoghurt fortified with 2% SPFL; T4: yoghurt fortified with 4% SPFL; CS1, CS2, CS3 and CS4: commercial yoghurt samples.

yoghurt samples (C, T0.5, T1, and T4). It's also worthy to note that the body & texture parameter in T2 was identical to that in the commercial sample CS3 (4.83). This result could be explained by the fact that SPFL and commercial stabilizers in CS3 had a comparable impact. Generally, the highest scores for all the sensorial evaluation parameters along with the storage period at 4˚C were noticed in commercial yoghurt CS3. Sweet potato flour has a distinct flavour profile, according to (Zhang *et al*. 2010) [17], and its inclusion in food compositions can result in a colour change and a pleasant taste. Sweet potato flour significantly increases taste score; the high patterns were different for individual yoghurt and their SPFL additions. The addition of 4% SPFL to yoghurt (T4) was adequate to transform the taste of the yoghurt into a budding taste. This is due to the SPFL's strong sweet taste and starchy texture. Furthermore, our results revealed that control yoghurt earned a medium overall acceptance score (17.92) at zero time of storage, owing to its flavour and delicate body & texture. The use of SPFL (T1 and T2), on the other hand, improved the body & texture, appearance, and flavour throughout the storage duration (**Table 2**). As, supplementing SPFL with milk resulted in an increase in the sensory attributes, especially consistency as cited by (Padmaja *et al*. 2012) [18] in the preparation of intermediary products food using sweet potato. There were no significant variations between the storage duration and the used treatments, according to the statistical analysis results. On the other hand, there was a considerable difference in the appearance of all the treatments along with the storage period. The favourable effect of sweet potato on the sensory indices that we observed in our results was consistent with previous research (Omar *et al*. 2019 and El-Aidie *et al*. 2021) [19] [20].

3.2. Physicochemical Analysis

As shown in (**Table 3**) that SPFL enrichment had no discernible effect on yoghurt fat content. During 0, 7, and 14 days of storage at 4˚C, the moisture and pH values in all samples gradually decreased. In the control sample, the change in pH along with the storage period (between zero and 14 days) was clearly visible (from 4.61 to 4.44, respectively). On the contrary, the lowest variations were noticed in CS2, CS1, and T2 (**Table 3**). So, it could be attributed to the pH stability in these previous samples along with the storage time. The decrease of moisture along with the storage was remarkably noticed in T0.5 (from 85.67% at zero time to 84.65%, at 14 days). While CS1 had the same moisture value in zero and 14 days of storage (85.22%). This stability could be attributed to its contents of the commercial stabilizers (E1442 and E440) and emulsifier (E471). The use of 1%, 2%, and 4% SPFL considerably reduced moisture loss of yoghurt both fresh and after storage, when compared to the control and T0.5 samples (**Table 3**). As a result, thickening agents like SPFL are being considered as a technique for controlling yoghurt syneresis. With increasing storage time, the protein content of all SPFL-enriched yoghurt samples (T0.5, T1, T2, and T4) gradually rose. The inclusion of sweet potato flour (3.1% protein, data not shown) may be responsible for the gradual rise in protein in treatment samples. While the presence of protein remained relatively constant during the storage time for all the commercial samples (CS1, CS2, CS3, and CS4).

Table 3. Physicochemical analysis of yoghurt enriched with different percentages of sweet potato (0%, 0.5%, 1%, 2% and 4%) and commercial yoghurt samples at zero 7 and 14 days of storage at 4˚C.

	Storage (days)	Treatments					Commercial samples			
		C	T0.5	T1	T2	T4	CS1	CS2	CS3	CS4
pH	Zero	4.66 ± 0.05	4.62 ± 0.04	4.61 ± 0.04	4.60 ± 0.03	4.61 ± 0.06	4.31 ± 0.01	4.21 ± 0.02	4.39 ± 0.02	4.27 ± 0.01
	7	4.58 ± 0.09	4.52 ± 0.01	4.52 ± 0.01	4.52 ± 0.01	4.53 ± 0.02	4.22 ± 0.01	4.18 ± 0.01	4.19 ± 0.03	4.18 ± 0.02
	14	4.44 ± 0.02	4.44 ± 0.01	4.44 ± 0.01	4.43 ± 0.02	4.43 ± 0.02	4.16 ± 0.01	4.067 ± 0.06	4.23 ± 0.01	4.10 ± 0.02
Fat %	Zero	3.30 ± 0.000	3.30 ± 0.00	3.40 ± 0.00	3.40 ± 0.00	3.40 ± 0.00	2.87 ± 0.06	3.1 ± 0.10	3.13 ± 0.15	3.50 ± 0.10
	7	3.3 ± 0.00	3.4 ± 0.00	3.5 ± 0.00	3.5 ± 0.00	3.5 ± 0.00	2.9 ± 0.10	3.03 ± 0.06	3.17 ± 0.15	3.43 ± 0.06
	14	3.4 ± 0.00	3.5 ± 0.00	3.6 ± 0.00	3.6 ± 0.00	3.6 ± 0.00	3.1 ± 0.10	3.2 ± 0.10	3.13 ± 0.15	3.5 ± 0.10
Moisture %	Zero	88.43 ± 0.11	85.67 ± 0.14	85.19 ± 0.13	84.70 ± 0.17	83.38 ± 0.11	85.22 ± 0.02	85.38 ± 0.03	84.82 ± 0.21	84.87 ± 0.15
	7	88.07 ± 0.05	85.29 ± 0.13	84.99 ± 0.06	84.6 ± 0.24	84.08 ± 0.09	85.19 ± 0.07	85.37 ± 0.02	84.65 ± 0.09	84.66 ± 0.07
	14	87.53 ± 0.23	84.65 ± 0.50	84.32 ± 0.57	83.8 ± 0.54	83.54 ± 0.61	85.22 ± 0.02	85.23 ± 0.02	84.62 ± 0.04	84.61 ± 0.03
Protein %	Zero	3.20 ± 0.01	3.27 ± 0.04	3.36 ± 0.07	3.48 ± 0.07	3.6 ± 0.07	3.07 ± 0.06	3.57 ± 0.15	4.03 ± 0.06	3.50 ± 0.10
	7	3.21 ± 0.02	3.39 ± 0.09	3.61 ± 0.15	3.77 ± 0.06	3.86 ± 0.05	3.10 ± 0.10	3.47 ± 0.06	4.00 ± 0.10	3.47 ± 0.06
	14	3.27 ± 0.03	3.37 ± 0.011	3.63 ± 0.23	3.93 ± 0.07	4.06 ± 0.07	3.27 ± 0.06	3.47 ± 0.06	4.1 ± 0.10	3.43 ± 0.06
Viscosity (mpsa)	Zero	4852 ± 2.00	5300 ± 2.00	5630 ± 2.00	5958 ± 2.00	6148 ± 2.00	8120.3 ± 4.51	8309.33 ± 3.05	7820.33 ± 2.52	8800 ± 3.00
	7	4825 ± 5.57	5246.67 ± 9.45	5569 ± 4.58	5947 ± 2.64	6171.67 ± 7.64	8150 ± 5.00	8302 ± 3.46	7840.33 ± 4.51	8779.33 ± 3.05
	14	4806.33 ± 3.51	5240 ± 9.16	5546.67 ± 11.59	5908 ± 2.00	6149.33 ± 4.04	8169 ± 3.61	8280.33 ± 3.51	7850.67 ± 1.15	8820.67 ± 3.05

C: yoghurt without sweet potato,; T0.5: yoghurt fortified with 0.5% SPFL; T1: yoghurt fortified with 1% SPFL; T2: yoghurt fortified with 2% SPFL; T4: yoghurt fortified with 4% SPFL; CS1, CS2, CS3 and CS4: commercial yoghurt samples.

The control sample (C) presented the lowest value of protein (3.20%, 3.21%, and 3.27% all over the storage period, respectively). On the other hand, CS3, T4, and T2 samples behaved an opposite trend (4%, 3.86%, and 3.77% after 7 days of storage, respectively). This result was in agreement with Omar *et al.* (2019) [19]. Viscosity showed a noticeable increase after 14 days of storage in CS1, CS3, CS4, and T4 (8169, 7850.67, 8820.67, and 6149.33 mPsa. These results could be explained by the impact of different types of stabilizers and emulsifiers used in commercial samples (CS1, CS3, and CS4), as well as the high SPFL concentration (4%) in T4. All of the yoghurt fortified with SPFL had greater viscosity values than the control, indicating a thicker structure (**Table 3**). These findings matched those of Saleh *et al.* (2020) [21]. As a result, SPFL has been added as one of the most important procedures in the production of yoghurts, with the potential to increase the viscosity and improve the body & texture of the yoghurt.

Effect of Adding SPFL on the WHC % and Colour of Yoghurt

Water holding capacity is an important parameter when evaluating yoghurt quality. The SPFL fortification resulted in increasing the WHC % in the supported yoghurt, compared to treatment C (**Table 4**) which acts as a thickening agent and had nutritive and healthy benefits (Donkor *et al.* 2020) [22]. At the end of the storage period at 4˚C, the values of WHC were nearly stable with no significant variations in treatments T1 and T2 (39.24% and 38.94%, 42.06%, and 41.64%, respectively). In contrast, T4 revealed a significant decay in the WHC value (42.78% and 39.41% at zero and 14 days of storage, respectively). These results propose that 1% and 2% SPFL had a positive effect on the water preservation of tested yoghurt. In this regard, Saleh *et al.* (2020) [21] found that adding

Table 4. Effect of adding different concentration of SPFL (0%, 0.5%, 1%, 2% and 4%) on water holding capacity and colour of yoghurt at zero and 14 days of storage at 4˚C.

	Storage (days)	Treatments				
		C	T0.5	T1	T2	T4
WHC %	Zero	36.2 ± 0.27	37.3 ± 2.32	39.24 ± 1.57	42.0 ± 0.34	42.78 ± 0.18
	14	36.79 ± 0.20	36.60 ± 1.81	38.94 ± 1.46	41.64 ± 0.30	39.41 ± 0.14
Colour						
L*	Zero	87.31 ± 0.32	86.71 ± 0.41	86.54 ± 0.21	85.07 ± 0.35	82.56 ± 0.46
a*		0.25 ± 0.08	0.59 ± 0.12	1.17 ± 0.24	2.23 ± 0.45	4.70 ± 0.35
b*		10.53 ± 0.10	11.07 ± 0.31	12.23 ± 0.24	14.8 ± 0.51	20.98 ± 0.33
L*	14	87.53 ± 0.40	86.21 ± 0.48	85.88 ± 0.38	83.47 ± 0.54	81.23 ± 0.20
a*		0.21 ± 0.07	0.89 ± 0.06	2.23 ± 0.14	3.57 ± 0.21	5.38 ± 0.43
b*		10.58 ± 0.20	11.53 ± 0.33	12.78 ± 0.28	15.64 ± 0.30	22.67 ± 0.25

C: yoghurt without sweet potato; T0.5: yoghurt fortified with 0.5% SPFL; T1: yoghurt fortified with 1% SPFL; T2: yoghurt fortified with 2% SPFL; T4: yoghurt fortified with 4% SPFL; L*: values (lightness or whiteness); a*: values (redness); b*: values (yellownes).

sweet potato starch to set yoghurt increased viscosity and decreased draining-off substantially. This could be owing to the starch gelatinization mechanism used in the first step of yoghurt production. Considering starch is made up of amylopectin molecules with strong water binding ability (Hartati *et al.* 2003) [23], it can increase the yoghurt viscosity (**Table 3**).

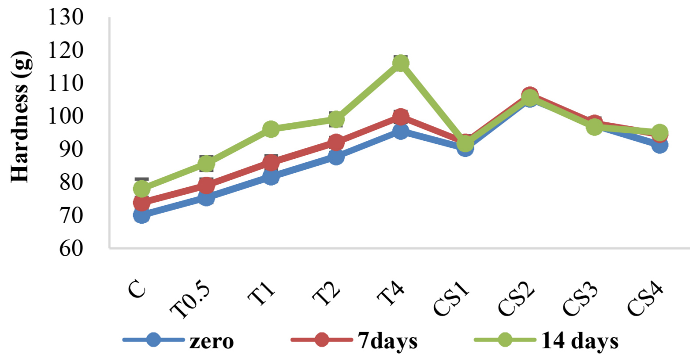
Along with its high amount of carotenoids and pleasant sensory features with colour, the orange-sweet potato has been attracting food technologists and nutritionists (Jenkins *et al.* 2015, Satheesh and Workneh 2019) [24] [25]. As shown in (**Table 2**), SPFL clearly provides sensory satisfaction in the aroma, taste, colour, and texture of food. The results in (**Table 4**) revealed that L* values (lightness or whiteness), were really decreased in samples with added 2% SPFL (85.07 and 83.47 at zero and 14 days of storage, respectively) compared with control yoghurt (87.31 and 87.53 at zero and 14 days of storage, respectively). When compared with control yoghurt, the values of a* (redness) and b* (yellowness) were significantly affected by SPFL addition. The a* values of tested yoghurt samples ranged from (0.59 to 4.70 and 0.89 to 5.38 at 0 and 14 days of storage, respectively). Also, the high SPFL concentration (2% and 4%) had a significant effect on b* values during the storage period (14.8, 20.98 and 15.64, 22.67 at zero and 14 days of storage, respectively). As a result, the growing a* and b* values, as well as the decreasing L* values, during the storage period could be linked to the high SPFL concentration as well as the decreasing moisture.

3.3. Texture Profile Analysis (TPA) of Yoghurt Samples

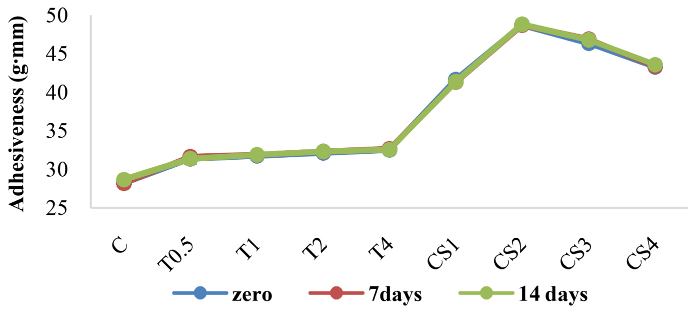
Double-bite compression tests were originally used to determine texture profiles. In practise, the two most important factors for texture characterisation are force (stress) and deformation (strain). Texture Profile Analysis (TPA) measures parameters such as chewiness, gumminess, cohesiveness, adhesiveness, and firmness (Chen and Stokes 2012, Srilakshmi 2020) [26] [27]. It is well known that texture has a vital role in the quality of fermented dairy products, and it is strongly influenced by their composition. **Figure 2** presents results variations in texture features of the yoghurt treatments estimated by texture profile analysis, compared to control yoghurt and commercial yoghurt samples (C, CS1, CS2, CS3, and CS4, respectively).

3.3.1. Effect on Hardness

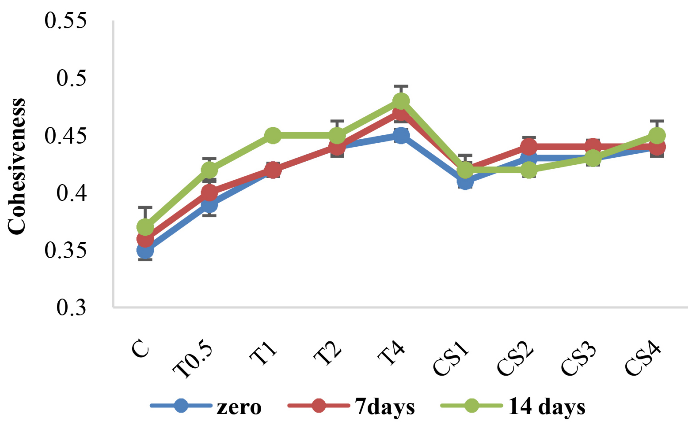
The most essential factor in determining the texture of yoghurt is its hardness. It is defined as the force required achieving a specific deformation and is used to determine the firmness of yoghurt. The rheological properties of produced yoghurt are immediately affected by any disturbance in the balance of milk components (Penna *et al.* 2006) [28]. In some cases, however, the inclusion of stabilisers is restricted. Hardness (g) of sweet potato fortified yoghurts ranged from 70 to 116 g depending on the varying of SPFL concentrations (**Figure 2(a)**). Supplementation of SPFL flour to be involved in the yoghurt matrix, has a significantly positive impact on the yoghurt hardness (70, 75.33, 81.67, 87.75, and 95.50 g


Hardness (g)
130
120
110
100
90
80
70
60
C
T0.5
T1
T2
T4
CS1
CS2
CS3
CS4
zero
7days
14 days

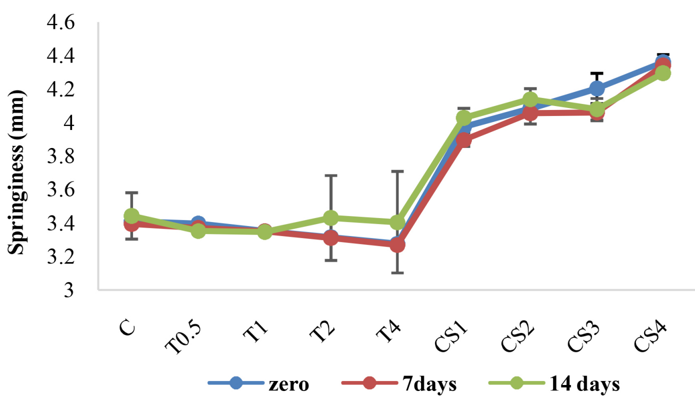
(a)


Adhesiveness (g·mm)
50
45
40
35
30
25
C
T0.5
T1
T2
T4
CS1
CS2
CS3
CS4
zero
7days
14 days

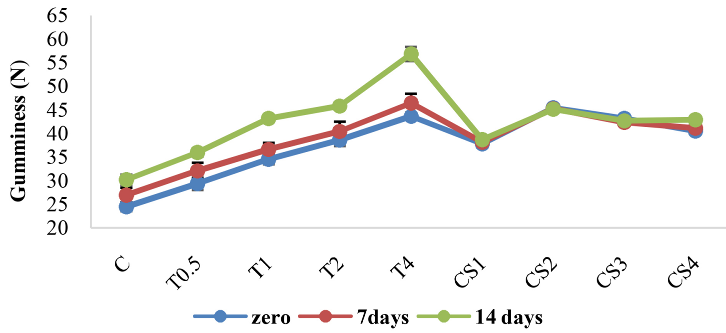
(b)


Cohesiveness
0.55
0.5
0.45
0.4
0.35
0.3
C
T0.5
T1
T2
T4
CS1
CS2
CS3
CS4
zero
7days
14 days

(c)


Springiness (mm)
4.6
4.4
4.2
4
3.8
3.6
3.4
3.2
3
C
T0.5
T1
T2
T4
CS1
CS2
CS3
CS4
zero
7days
14 days

(d)



(e)

Figure 2. Texture profile analyses of yoghurt samples during the storage at zero, 7 and 14 days at 4˚C. (a) Hardness; (b) Adhesiveness; (c) Cohesiveness; (d) Springiness; (e) Gumminess. C: yoghurt without sweet potato; T0.5: yoghurt fortified with 0.5% SPFL; T1: yoghurt fortified with 1% SPFL; T2: yoghurt fortified with 2% SPFL,; T4: yoghurt fortified with 4% SPFL; CS1, CS2, CS3 and CS4: commercial yoghurt samples.

for C, T0.5, T1, T2, and T4 at zero time). Moreover, enriched yoghurt recorded higher values of the hardness along with the storage period especially for T4 (95.5, 99.75, and 116 g at zero, 7, and 15 days, respectively). The highest physical interaction between the starch and the casein (Saleh *et al.* 2020) [21] possibly explain this outcome. Increased yoghurt hardness had a significant impact on yoghurt production, as sweet potato flours were used to replace the industrial stabiliser. From Figure 2(a) and Table 4 we can observe that the use of SPFL led to high values of hardness as well as increased the WHC % (decreasing the syneresis of yoghurt). This observation restricts the interaction of sweet potato and milk components to make the desired texture of yoghurt, especially in T2 and T4. This finding could also be accredited to the high amylose content capable of forming a stronger network. (Saleh *et al.* 2020) [21]. The yoghurt hardness of T4 was nearly in behaviour to that of the CS3 sample (95.5, 97.75, and 99.75, 97.75 g at zero and 7 days of storage, respectively). According to the texture analyses data, yoghurt supplemented with the SPFL (T2 and T4) exhibited the best texture among other SPFL-enriched yoghurt and control. So, this gains a positive consideration of adding SPFL to improve the yoghurt texture. Sweet potato fortification in yoghurt is thus suggested as an applicable approach to improve the rheological properties of yoghurt products. It was noticed stability of determining hardness along with storage period at 4˚C in commercial yoghurt samples (CS1, CS2, CS3, and CS4), that because of using commercial stabilizers as well as emulsifiers in these samples.

3.3.2. Effect on Adhesiveness

The force required to remove the adhered substance from the mouth during chewing is referred to as adhesiveness. It is used as a measure of yoghurt stickiness and is contrariwise related to yoghurt eating quality (Mousavi *et al.* 2019) [1]. Sweet potato yoghurt adhesiveness (g·mm) ranged from 28.19 to 32.64 g·mm, depending on the amount of SPFL. The effect of the different SPFL concentrations on the adhesiveness is shown in (**Figure 2(b)**). We believe that the viscosity of the yoghurt increases with SPFL supplementation led to the stickiness of yoghurt. The adhesiveness of the yoghurt increased gradually upon the addition of sweet potato when compared to the control sample (28.22, 31.88, 32.29, and 32.64 g·mm for 0%, 1%, 2%, and 4% SPFL at 7 days of storage, respectively). The stable behaviour of all tested samples was noted along with the storage period at zero, 7, and 14 days at 4˚C.

3.3.3. Effect on Cohesiveness

The strength of internal bonds is measured by cohesiveness, which is the extent to which a material may be deformed before it ruptures (Srilakshmi 2020) [27]. It is related to the consumer acceptability of yoghurt and is an important parameter for analysing the yoghurt texture. The cohesiveness changes of yoghurt associated with the addition of different levels of SPFL are shown in **Figure 2(c)**. When compared to control yoghurt at zero, 7, and 14 days of storage, the yoghurt's cohesiveness increased sluggishly with increasing SPFL content (0.46, 0.47, 0.48, and 0.35, 0.36, and 0.37 for T4 and C, respectively). Similar results were observed when yoghurt was supplemented with oat-maltodextrin (Domagala *et al.* 2005) [29]. The increase in cohesiveness with SPFL supplementation could be due to viscosity imparted by sweet potato which could provide strength to the yoghurt structure (Mudgil *et al.* 2017) [30]. This rise could also be attributable to SPFL's high carbohydrate content (73.01%, result not shown), which could help the yoghurt maintain its structural integrity. It's worth noting that, the protein matrix plays a crucial function in the cohesion of the body (Tunick 2000) [31]. The same stable adhesiveness behaviour of all tested samples was observed in the cohesiveness parameter along with the storage period, especially at zero and 7 days of storage at 4˚C.

3.3.4. Effect on Springiness

The rate at which the sample recovers to its original dimensions after the deforming force is eliminated is known as springiness. **Figure 2(d)** shows that as the concentration of SPFL in yoghurt increased, the values of springiness decreased gradually. The maximum value of springiness was found at the lowest level of SPFL (T0.5, 3.39 mm at 7 days of storage). In the maximal SPFL concentration, on reverse, the smallest springiness value was (T4, 3.27 mm at 7 days of storage). This is due to the high carbohydrate content of the yoghurt, which causes the increase in yoghurt consistency. Throughout the storage period, the highest levels of springiness were seen in all commercial samples (CS1, CS2, CS3, and CS4). This could be associated with the effect of adding stabilizers (E440 and E1442) and emulsifiers (E471) in yoghurt formulations.

3.3.5. Effect on Gumminess

Another essential parameter for yoghurt textural research is its gumminess. The level of gumminess acceptance in yoghurt depends on the consumer acceptability. It may vary from person to person. Gumminess of yoghurt increased upon the increase in concentrations of SPFL (**Figure 2(e)**). The highest level of SPFL (T4) showed the highest values of gumminess (43.69, 46.42, and 56.85 N, at zero, 7, and 14 days of storage, respectively). Gumminess is related to hardness of yoghurt as yoghurt showed the higher values of the hardness behaviour the same in gumminess (**Figure 2(a)** and **Figure 2(e)**). This result is consistent with (El-Aidie *et al.* 2021) [20].

The results obtained from **Figure 2** revealed that yoghurt fortified with SPFL showed more cohesive and gummy when compared to the control yoghurt and other treatments. Consequently, SPFL can take the role of industrial stabilisers.

3.4. Microstructural Characterization of Yoghurt Samples

It is well recognized that the structure of foods greatly affects their various properties including texture, functionality, and appearance. The microstructure has a major impact on the texture and other physical properties of acid milk gels. The network has pores or void spaces in which the aqueous phase is confined. In fat-containing products, the presence of (large) fat globules obscures the finer details of pores and strands. (**Figures 3(a)-(e)**) illustrated Scanning Electron Micrograph (SEM) of yoghurt fortified with SPFL using different concentrations. The different behaviour of control (**Figure 3(a)**) compared with SPFL on yoghurt (**Figures 3(b)-(e)**) gel texture was due to the specific properties of these substances and their different ways of interfering with the formation of the protein network. The different behaviours cause casein micelles and denatured whey proteins aggregates which form a three-dimensional network during fermentation. It was observed that the microstructure of yoghurts with SPFL showed a denser and smaller void when compared with control yoghurts and was noticed that the sweet potato globules were embedded in and connected to the gel matrix. The addition of 0.5% SPFL (**Figure 3(b)**) caused no observable change in the yoghurt structure. Comparatively, the intact gelatinous network that almost formed sheets of (SPFL) demonstrated in (**Figure 4(a)** and **Figure 4(b)**), was fused into aggregates and microparticles larger than the casein micelles which interfered with the protein network affecting negatively on fortified yoghurt structure. These changes were reflected in sensory evaluation scores except for the concentration of 2% (**Table 2**) and texture profile analyses (**Figure 2**). The addition of 2% SPFL (**Figure 3(d)**) appeared under scanning electron microscopy in the form of short fibres and sheets. The fibres frequently had free terminations and only some of them were connected with small clusters of casein micelles. Also, fat globules are spread uniformly. Yoghurt with an SPFL case of concentration 4% (**Figure 3(e)**) formed a markedly fibrillary microstructure that connected large clusters of casein micelles. The fibres were thin and long and no free terminations were observed. Consequently, fat globules are markedly less appeared as they enclosed inside the large clusters. Also, T4 appeared relatively uniform, fused surface, and oval-shaped with a longitudinal groove and fewer voids in comparison to concentrations of 2%, 1%, and 0.5% respectively.

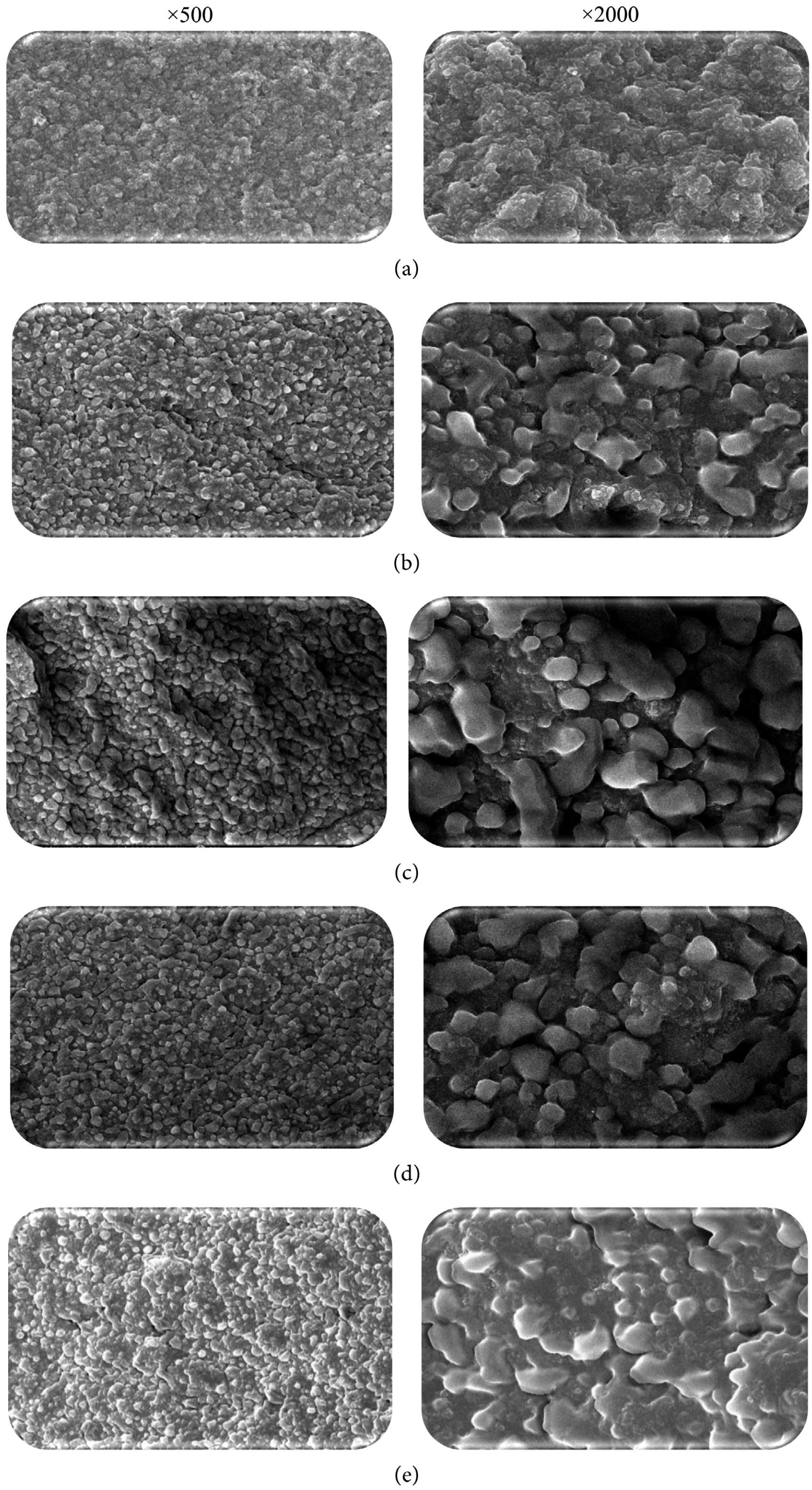


Figure 3. Scanning Electron Micrograph (SEM) of yoghurt fortified with different percentages of SPFL, ×500 and ×2000. (a) Scanning SEM of control yoghurt full fat cow milk (C); (b) Scanning SEM of yoghurt fortified with 0.5% SPFL (T0.5); (c) Scanning SEM of yoghurt fortified with 1% SPFL (T1); (d) Scanning SEM of yoghurt fortified with 2% SPFL (T2); (e) Scanning SEM of yoghurt fortified with 4% SPFL (T4).

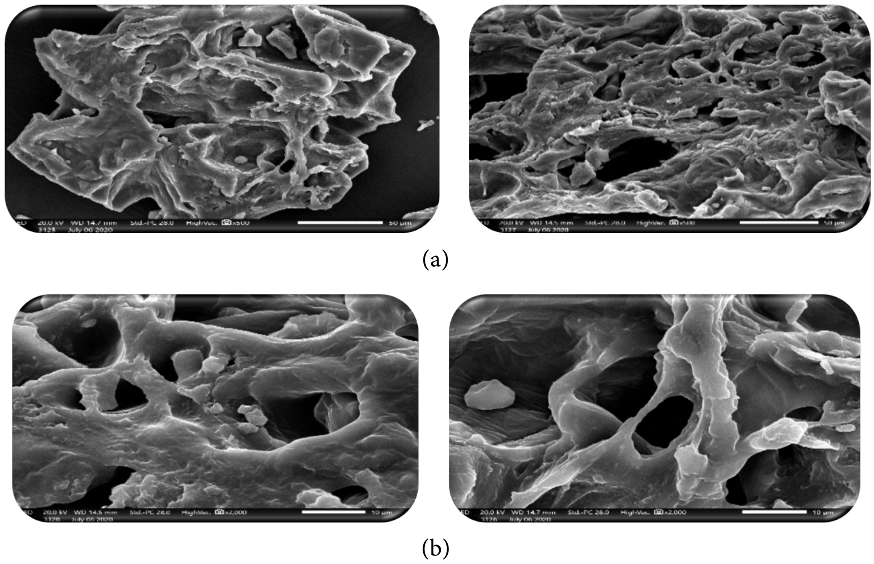


Figure 4. Scanning Electron Micrograph (SEM) of SPFL. (a) Sweet potato flour dehydrated in lab (SPFL) ×500; (b) Sweet potato flour dehydrated in lab (SPFL) ×2000.

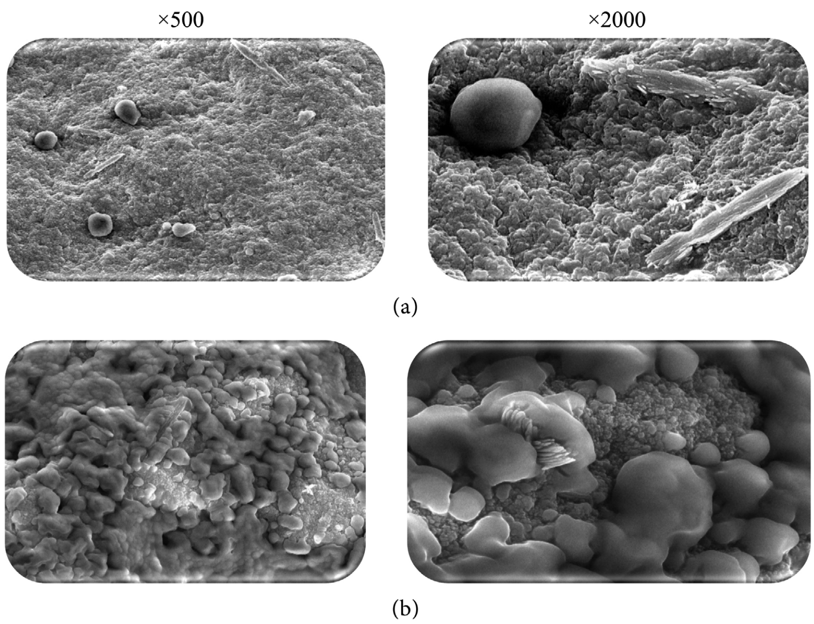


Figure 5. Scanning Electron Micrograph (SEM) of commercial yoghurt samples (CS1 and CS3), ×500 and ×2000. (a) Scaning SEM of CS1; (b) Scaning SEM of CS3.

SPFL fortified yoghurt (**Figure 3(d)**) was found to be more similar to the commercial sample (**Figure 5(b)**). On the other hand, the control sample (**Figure 3(a)**) exposed intact sheets like structure which could affect sensory evaluation. This result indicated that the fortified SPFL yoghurt samples can self-organize through yoghurt structure and is less effective.

4. Conclusion

Sweet potato flour supplementation affects significantly the quality of the set yoghurt. As a matter of fact, the addition of 2% SPFL led to an increase in both hardness and gumminess, stable WHC % values are also noticed. Improvement of the body, texture, appearance, and flavour was also observed all over the storage period of yoghurt. The yoghurt obtained using 2% SPFL was comparable to commercial yoghurt samples (CS1 and S3) using a significantly cheaper natural stabilizer. It is therefore recommended to develop an industrial production unit of sweet potato dehydrated flower to improve yoghurt functional properties.

Acknowledgements

This work is based upon a project entitled: Technological and Healthy Impacts of Yogurt Fortified with Sweet Potato roots. Supported by Science & Technology Development Fund (STDF), Ministry of Scientific Research. Egypt, under a grant (innovation). Project ID 26348.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] Mousavi, M., Heshmati, A., Daraei Garmakhany, A., Vahidinia, A., and Taheri, M. (2019) Texture and Sensory Characterization of Functional Yogurt Supplemented with Flaxseed during Cold Storage. *Food Science and Nutrition*, **7**, 907-917. https://doi.org/10.1002/fsn3.805

[2] García-Pérez, F., Lario, Y., Fernández-López, J., Sayas, E., Pérez-Alvarez, J. and Sendra, E. (2005) Effect of Orange Fiber Addition on Yogurt Color during Fermentation and Cold Storage. *Color Research and Application*, **30**, 457-463. https://doi.org/10.1002/col.20158

[3] Sadeghi, A. (2016) *In Vitro* Assessment of Some Probiotic Properties of *Lactobacillus fermentum* Isolated from Pickled Garlic. *Journal of Food Quality and Hazards Control*, **3**, 67-72.

[4] Okoye, J.I. and Obi, C.D. (2013) Effect of Sweet Potato Starch Addition on the Proximate Composition, Energy Contents and Sensorial Properties of Stirred Yoghurt. *International Journal of Science and Research*, **5**, 929-931. https://doi.org/10.21275/v5i5.NOV163434

[5] El-Sayed, E.M., Abd El-Gawad, I.A., Murad, H.A. and Salah, S.H. (2002) Utilization of Laboratory-Produced Xanthan Gumin the Manufacture of Yogurt and Soy Yogurt. *European Food Research Technology*, **215**, 298-304. https://doi.org/10.1007/s00217-002-0551-9

[6] Ortiz, Y., García-Amézquita, E., Acosta, C.H. and Sepúlveda, D.R. (2017) Functional Dairy Products. In: Barbosa-Cánovas, G.V., *et al*., Eds., *Global Food Security and Wellness*, Springer Science + Business Media, New York, 67-103. https://doi.org/10.1007/978-1-4939-6496-3_5

[7] FAOSTAT (2016) Production Quantity. Food and Agricultural Organization. http://www.fao.org/faostat/en/#data/QC

[8] Mu, T.-M. and Singh, J. (2019) Sweet Potato: Origin and Production. In: Mu, T.-H. and Singh, J., Eds., *Sweet Potato Chemistry*, *Processing*, *and Nutrition*, Academia

Press, Cambridge,5-25. https://doi.org/10.1016/B978-0-12-813637-9.00002-8

[9] ISO 22935-3|IDF 099-3 (2009) Milk and Milk Products-Sensory Analysis. Part 3: Guidance on a Method for Evaluation of Compliance with Product Specifications for Sensory Properties by Scoring. ISO and IDF, 7 p.

[10] AOAC (2010) Official Methods of Analysis. 18th Edition, Association of Official Analytical Chemists International, Benjamin Franklin Station, Washington DC.

[11] Seçkin, A.K. and Baladura, E. (2012) Effect of Using Some Dietary Fibers on Color, Texture and Sensory Properties of Strained Yogurt. *Gida*, **37**, 63-69.

[12] Nilsson, L., Lyck, S. and Tamime, A. (2006) Production of Drinking Products. In: Tamime, A., Ed., *Fermented Milks*, Blackwell Science, Oxford, Vol. 5, 95-127.

[13] Saffon, M., Richard, V., Jiménez-Flores, R., Gauthier, S.F., Britten, M. and Pouliot, Y. (2013) Behavior of Heat-Denatured Whey: Buttermilk Protein Aggregates during the Yogurt-Making Process and Their Influence on Set-Type Yogurt Properties. *Foods*, **2**, 444-459. https://doi.org/10.3390/foods2040444

[14] Bourne, M.C. (2002) Food Texture and Viscosity: Concept and Measurement. 2nd Edition, Elsevier Science & Technology Books, Amsterdam.

[15] Szczesniak, A.S. (1963) Classification of Textural Characteristics. *Journal of Food Science*, **28**, 385-389. https://doi.org/10.1111/j.1365-2621.1963.tb00215.x

[16] Puvanenthiran, A., Williams, R. and Augustin, M. (2002) Structure and Viscoelastic Properties of Set Yoghurt with Altered Casein to Whey Protein Ratios. *International Dairy Journal*, **12**, 383-391. https://doi.org/10.1016/S0958-6946(02)00033-X

[17] Zhang, W., Sun, C., He, F. and Tian, J. (2010) Textural Characteristics and Sensory Evaluation of Cooked Dry Chinese Noodles Based on Wheat Sweet Potato Composite Flour. *International Journal of Food Properties*, **13**, 294-307. https://doi.org/10.1080/10942910802338194

[18] Padmaja, G., Jaffer, T.S. and Sajeev, M.S. (2012) Food Uses and Nutritional Benefits of Sweet Potato. *Fruit, Vegetable and Cereal Science and Biotechnology, Global Science Books*, **6**, 115-123.

[19] Omar, H.H., El-Nimer, A.M.M., Ahmed, A. and Hassaan, H.M.H. (2019) Production of Functional Bio Yoghurt Made from Camel Milk, Skim Milk Retentate and Fortified with Sweet Potato Powder. *Egyptian Journal of Agriculture Research*, **97**, 441-458. https://doi.org/10.21608/ejar.2019.150727

[20] El-Aidie, S., Elsayed, N., Hashem, M. and Elkashef, H. (2021) Development of Fermented Skimmed Milk Fortified with Yellow Sweet Potato (*Ipomoea batatas* L.) with Prebiotic and Antioxidant Activity. *Journal of Food and Nutrition Research*, **60**, 66-75.

[21] Saleh, A., Mohamed, A.A., Alamri, S.M., Hussain, Sh., Qasem, A.A. and Mohamed, A.I. (2020) Effect of Different Starches on the Rheological, Sensory and Storage Attributes of Non-Fat Set Yogurt. *Foods*, **9**, 61-74. https://doi.org/10.3390/foods9010061

[22] Donkor, E.A., Donkor, E., Sekyere, E.O. and Owusu, V. (2020) The Development and Promotion of Sweet Potato Yoghurt in Ghana: Implications for Sustainable Production and Consumption Policies. *Sustainability*, **12**, Article No.3336. https://doi.org/10.3390/su12083336

[23] Hartati, N.S. and Prana, T.K. (2003) Analysis of Starch and Crude Fiber Content of Several Cultivars of Taro (*Colocasia esculenta* L. Shott). *Journal Nature Indonesia*, **6**, 29-33.

[24] Jenkins, M., Byker Shanks, C. and Houghtaling, C. (2015) Orange-Fleshed Sweet

Potato: Successes and Remaining Challenges of the Introduction of a Nutritionally Superior Staple Crop in Mozambique. *Food Nutrition Bulletin*, **36**, 327-353. https://doi.org/10.1177/0379572115597397

[25] Satheesh, N. and Workneh, S. (2019) Review on Nutritional Composition of Orange-Fleshed Sweet Potato and Its Role in Management of Vitamin A Deficiency. *Food Science and Nutrition*, **7**, 1920-1945. https://doi.org/10.1002/fsn3.1063

[26] Chen, J., Jason and Stokes, R. (2012) Rheology and Tribology: Two Distinctive Regimes of Food Texture Sensation. *Trends in Food Science & Technology*, **25**, 4-12. https://doi.org/10.1016/j.tifs.2011.11.006

[27] Srilakshmi, A. (2020) Texture Profile Analysis of Food and TPA Measurements: A Review Article. *International Research Journal of Engineering and Technology* (*IRJET*), **7**, 708-711.

[28] Penna, A.L.B., Gurram, S. and Canovas, G.V.B. (2006) Effect of High Hydrostatic Pressure Processing on Rheological and Textural Properties of Probiotic Low Fat Yogurt Fermented by Different Starter Cultures. *Journal Food Processing Engineering*, **29**, 447-461. https://doi.org/10.1111/j.1745-4530.2006.00076.x

[29] Domagala, J., Sady, M., Grega, T. and Bonczar, G. (2005) The Influence of Storage Time on Rheological Properties and Texture of Yoghurts with the Addition of Oat-Maltodextrin as a Fat Substitute. *International Journal Food Properties*, **8**, 439-448. https://doi.org/10.1080/10942910500267489

[30] Mudgil, D., Barak, Sh. and Khatkar, B.S. (2017) Texture Profile Analysis of Yogurt as Influenced by Partially Hydrolysed Guar Gum and Process Variables. *Journal Food Science and Technology*, **54**, 3810-3817. https://doi.org/10.1007/s13197-017-2779-1

[31] Tunick, M. (2000) Rheology of Dairy Foods that Gel, Stretch, and Fracture. *Journal of Dairy Science*, **83**, 1892-1898. https://doi.org/10.3168/jds.S0022-0302(00)75062-4