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Chemical and Textural Modifications of Fortified Yogurt by Oat Powder

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Abstract:

The current research studied the properties of stirred yogurt, its composition, texture, rheology, and morphology, after fortification with varying levels of oat powder. Yogurt samples were prepared with 1%, 2%, 3% and 5% added oat powder and tested at multiple time points. The chemical analysis of these samples showed increases in total solids, dietary fibre and ash with increasing levels of oat powder, while the concentration of protein decreased due to dilution. oat supplementation did not influence the fermentation process or the rate at which it occurred, as there were no differences in pH between control and oat fortified yogurts. The textural analysis of the yogurts showed significant decreases in hardness and improvements in cohesiveness with increasing amounts of oat powder used in the formulation. Significant increases in water holding capacity (WHC) of the yogurt occurred with the addition of oat powder; this will result in greater moisture retention and reduction of syneresis. The results from FT-IR spectroscopy were consistent with these findings and suggested an embedding of polysaccharides within the yogurt matrix without altering the milk proteins. Viscosity showed non-linear behavior; thus, yogurt samples supplemented with high oat fiber concentration (5%) regained their flowability by virtue of polysaccharide networks. Consequently, oat powder fortification at 3-5% concentration could be an interesting approach in designing high fiber-added functional yogurt products having better composition and characteristics.

Keywords: *oat-fortified yogurt, fiber, viscosity, FTIR.*

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1. Introduction

One of the most popular fermented dairy products consumed worldwide is yogurt. Being classified as a functional food, it has always been prized for its high nutritional value and potential health benefits. During processing, milk is fermented with lactic acid bacteria, mainly Lactobacillus bulgaricus and Streptococcus thermophilus (Lee & Lucey, 2010). Numerous research have examined how adding functional ingredients to yogurt might improve both its nutritional value and health benefits (Tian et al., 2014).

Health-conscious consumers also believe that consumption of yogurt is beneficial due to both its antioxidant properties as well as its ability to prevent diarrhea. Additionally, yogurt consumption might offer protection against cancer; it also helps to optimize mineral absorption and prevent osteoporosis (Tutunchi et al., 2022). It is mostly because of the bacteria contained in the yogurt that most of these health advantages exist.

Another well-established benefit to our health is a diet rich in fiber. The recommended daily allowance is approximately 25 grams for women and 38 grams for males (Trumbo et al., 2002). Fiber Supplementing dairy products like yoghurt would create a plethora of opportunities for a meal to be both nutrient-dense and delicious in both texture and flavour.

Fiber in our diet helps in reducing the possibilities of various lifestyle diseases and is itself the indigestible portion of our diet (Arora et al., 2015).

Several studies have indicated that supplementing yogurt with dietary fibers may enhance its specific functionality. Obesity, diabetes, cancer, hypercholesterolemia, intestinal diseases, colonic diverticulosis, constipation, ulcerative colitis, hyperlipidaemia, hypertension, and heart conditions have all been linked to the use of fiber-rich yogurt (Dello Staffolo et al., 2004).

This study investigates the impact of adding oat powder in four different concentrations on the viscosity, texture, and physicochemical properties of yogurt.

2. Materials and Methods

2.1 Materials

Fresh milk from cows (total solid 13.10, fats 3.84%, protein 3.61%, acidity 0.87), was procured from Animal production Department, College of Agricultural Engineering Sciences, University of Sulaimani, Sulaymaniyah, Iraq. Lactic bacteria cultures, was purchased from local mark which contain (Streptococcus thermophilus and Lactobacillus Bulgaricus), was used in the laboratory conditions to produce the yoghurt. Oat powder (8.98% fiber, 3.92% Ash, and 10.06% protein), are presented as a dark white homogeneous powder was purchased from local market of Sulaymaniyah, used in different concentration 0% (control), 1%, 2%, 3%, and 5% .

2.2 Preparation of bovine milk yoghurt fortified with Oat powder

The raw bovine milk was thoroughly mixed with oat powder at three fortification levels—0% (as control), 1%, 2%, and 3%. The mixture was heated to 85–90°C for 30 minutes, cooled to 40–43°C, inoculated with a standard, incubated overnight at 37–38°C, and then chilled and refrigerated for additional analysis. The yogurt made using the technique outlined by (Ghadge et al., 2008) with some modification.

2.3 Chemical properties of fortified yoghurt

Total solids, moisture, protein, ash, fiber, pH, and acidity were all examined in the manufactured yoghurt samples. Yogurt's pH was determined using a digital pH meter (Global model DPH-500). The process of determining the acidity, solids, moisture, protein, ash, and fiber content (International, 2000).

2.4. Texture analysis

An examination of the texture profile of yogurt Texture characteristics including cohesiveness and hardness (firmness) were measured using a texture analyzer of the type (CT3,4500, Brookfield Engineering Lab). The method described by (Ibrahim et al., 2023) was used to assess the stiffness at 5 °C with a load strength of 5 kg. The yogurt sample was pressed at a constant rate of 1 mm/s using a cylindrical probe that measured 20 mm in diameter and 10 mm in depth .

2.5 . Fourier transform infrared (FTIR)

FTIR spectra of yoghurt samples were obtained using an FTIR spectrometer (FTIR spectrometer Alpha, Brucker Optik GmbH, Ettlingen/Germany) according to the method described by (Maghazechi et al. 2022), with slight modifications to obtain the FTIR Spectrum of yoghurt samples. Yoghurt sample (1 mg) was combined with potassium bromide (KBr) (100 mg), compressed into tablets of 1 cm diameter and scanned on the FTIR machine at a resolution of 2 cm-1, scanning from 4000 to 380 cm-1.2.6 Water holding capacity

The water-holding capacity of yogurt (WHC) was assessed using a method described by Kose et al. (2018). A sample of yogurt was centrifuged at 10g for 10 minutes at 5°C, and the amount of water removed as a result was calculated by measuring the weight of the supernatant liquid. The WHC was then calculated according to the following formula:

WHC % = [1-(w2 / w1)] ×100

w1]: weight of yoghurt used, and w2: weight of whey after centrifugation.

2.7 Viscosity determination

A glass rod was used to break up the yoghurt gel in order to determine its viscosity (10 times clockwise and 10 times counterclockwise). A Brookfield viscometer (model DV-E; Brookfield Engineering Laboratories) with spindle No. 7 was used to determine rotational viscosity. Every measurement was taken for one minute at room temperature and 100 rpm (Kose et al., 2018).

2.8 Sensory Evolution

For sensory evaluation, 15 trained panellists from Food Science and Quality control department, University of Sulaymaniyah were selected. Panellists scored the sample based on three attributes, Appearance evaluated from 10 points, Body and texture from 30 points, and flavours from 60 points (Kawani et al., 2022).

2.9. Statistical analysis

As a general test, the data were statistically analyzed using the analysis of variance approach. The XLSAT program version 7.5.2 was used to run a factorial experiment with three replications using Complex Randomized Design (CRD). After they demonstrated their significance in the general test, all potential comparisons between the means were performed using the Dunkin test at the significant threshold of 0.05.

3.Result and Discussion:

3.1 Chemical properties of fortified yoghurt

Table 1 shows that adding oats to yogurt alters its chemical makeup while keeping its pH steady. The total solid matter increases gradually as the composition percentage of oat increases from 14.07% in the control to 17.086% at a 5% oat composition. This observation is consistent with the result that the addition of cereals increases the Total solids percentages content and subsequently the yoghurt nutritional value and texture (Alqahtani et al., 2021).

There is a decline in the protein content with the level of oats added; it decreased from 4.56% in the control to 3.67% in the 5% oats. Such a decline can be explained by the dilution phenomenon whereby the proportion of milk proteins is lowered as the cereal solute is added in increased amounts. Such trends have also been recorded in a study whereby yogurt's protein content and physical characteristics were affected by the addition of oat protein concentrate. (Hashim, 2025).

The sample with 5% oats, indicated a pronounced increase in fibre content to 5.67%. Therefore, this study supports the notion of oats being an excellent source of dietary fibre fortification, due primarily to their β-glucan content, which has already been identified as having the ability to improve gastrointestinal function and increase satiety. In addition, prior research done on goat's milk yogurt that has been fortified with oat flour has shown the same dramatic increases in fibre and bio-functional properties, including antioxidant potential (Alqahtani et al., 2021). There was also a slight increase in the ash content of these products (0.6% to 0.93%), indicating how many minerals are found in oats as well as how many more minerals can be found in cereals-enriched yogurts (Bayram, 2025).

While for the pH values for the different treatments, there were similarities between the samples, as the values ware between 4.12 to 4.20, suggesting that adding oats did not have an effect on how the fermentation process occurred. This indicates that the osmotic pressure from adding oats and the fact that oats themselves contain a low amount of fermentable carbohydrates will not influence the ability of lactic acid bacteria to grow, which is also supported by other previous studies in regards to developing oat-supplemented recipes for lactic acid bacteria-enriched yogurt (Hashim, 2025).Overall, oats fortification is an effective method for obtaining fiber-enriched yoghurt products with improved nutritional properties. While the noted decrease in protein content is an aspect worth consideration, the simultaneous increase in dietary fiber, mineral content, as well as the fermentation stability, support the production of health-oriented functional yoghurt products.

Table 1. The chemical composition with pH values of yogurt (control) and fortified yoghurt with (1%, 2%, 3%, and 5%) oat ,

Samples	Total solids%	Moisture%	Protein%	Fiber%	Ash%	pH
Control	14.07 ± 0.01	85.93±0.1	4.56±0.02	0.0±0.00	0.6±0.02	4.14±0.01
%1oat	14.53 ± 0.01	85.47±0.02	4.13±0.01	3.31± 0.02	0.7±0.01	4.16±0.01
%2 oat	15.27± 0.02	84.73±0.02	4.16±0.1	3.78±0.01	0.73±0.01	4.14±0.01
%3 oat	15.92 ±0.02	84.08±0.02	3.85±0.01	4.72±0.01	0.85±0.01	4.2±0.01
%5 oat	17.09±0.01	82.91±0.02	3.67±0.02	5.67±0.01	0.93±0.02	4.12±0.01

3.2 Texture analysis

Fortifying the yogurt with oat powder significantly affects texture, as shown in Figure 1, with progressive increases in both firmness and cohesiveness with increasing concentrations of oats and storage time. Although the oat protein fraction alone will contribute protein, the use of whole oat will not only contribute protein but also fibers such as β-glucan, which is an important component influencing the matrix composition of yogurt.

The measured values of increased firmness (Figure 1a) with increasing levels of oat incorporation (up to 5%) indicate that the fibrous materials in whole oats contribute to a better functionality of the gel network by enhancing water retention as well as protein-polysaccharide interactions. β-glucan, a soluble fiber in oat, is well recognized for its functionality in forming a viscous solution with strong interactions with milk proteins due to hydrogen bonding and entanglement, leading to an improvement in gel strength and prevention of whey separation (Raikos et al., 2020) . The values of low acidification rate and higher firmness at seven days of storage also emphasize that oat fibers help in stabilizing the yogurt matrix with respect to pH buffering and prevention of proteolysis (Bulut et al., 2023).

Cohesiveness was also higher in the oat concentrate added groups (Figure 1b), and it could be that the role of oat fibers in improving water-binding properties and contributing towards the connectivity of the structure is mainly responsible for the observed increases. It is well documented that a higher addition of fibers aids in the development of a higher concentration of protein that is more closely interconnected and able to withstand degradation during storage (Ismail et al., 2020). It can be assumed that the combined roles of milk protein and oat polysaccharide are responsible for the observed increases.

These findings are in line with previous studies indicating the positive effects of cereal fibers, in particular oat fibers, in improving the texture properties and syneresis and acceptability of yogurts (Brückner-Gühmann et al., 2018). More important is the fact that using whole oats not only increases acceptability but also provides other benefits to the diet in terms of increased consumption of dietary fibers and uses as a prebiotic ingredient in improving gut-related functions (Mäkinen et al., 2015).

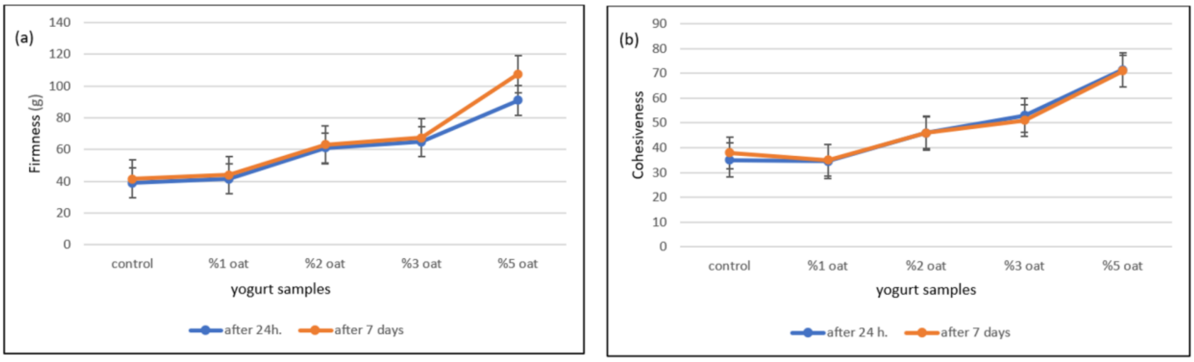

Figure 1. (a) Firmness values for yogurt control and oat fortified yogurt (%1, %2, %3, and %5) samples. (b) Cohesiveness ratio for yogurt control and oat fortified yogurt (%1, %2, %3, and %5) samples.

3.3 Fourier transform infrared (FTIR)

The main yoghurt components are presented in the FTIR spectrum (Figure 2), which also shows how FTIR spectroscopy was used to identify changes in the chemical composition (Maghazechi et al., 2022), thereby clarifying the role of oat addition in modifying the molecular structure of yoghurt across different concentration levels at 1%, 2%, 3%, and 5%. The O-H stretches around 3200-3600 cm^{-1} can be assigned to polysaccharides and water. It was expected that β-glucans in oats rely on hydrogen bonding and bound water for increased intensity and broadening. Moderate intensity of the O-H peak at around 3300 cm^{-1} suggests proper water binding without extensive dilution of the protein peak. At the same time, peak assignments around 2850-2950 cm^{-1}, corresponding to C-H stretches, could be attributed to lipid and alkyl functions. Pronounced variations indicate matrix rearrangement and interaction between fat and polysaccharides. Additionally, peaks around 1730-1750 cm^{-1} for the carbonyl function indicate lipid esters, and unaltered peaks indicate an unaltered lipid matrix. The Amide I (1650 cm^{-1}) and Amide II (1540 cm^{-1}) peaks verify the existence of protein secondary structures. Furthermore, there may also be interactions between the proteins from milk and the compounds from oats that will alter the arrangement of secondary structures of proteins via hydrogen bonding (Gallagher, 2009). Extreme variation and the reduction of intensity would indicate the denaturation of protein and changes in hydration. The same findings could hold true for β-glucans and starch polysaccharides in relation to the absorption of carbohydrates at approximately 1200-900 cm^{-1}, with greater peaks indicating a more successful incorporation of oats into products.

The distinct differences found between Amide I (~1650 cm^{-1}) and Amide II (~1540 cm^{-1}) bands demonstrate the presence of an intact protein matrix. In addition, the increased absorbance in the 1200 to 900 cm⁻¹ range supports the assumption that β-glucan/polysaccharides are also more prevalent in the treated samples .

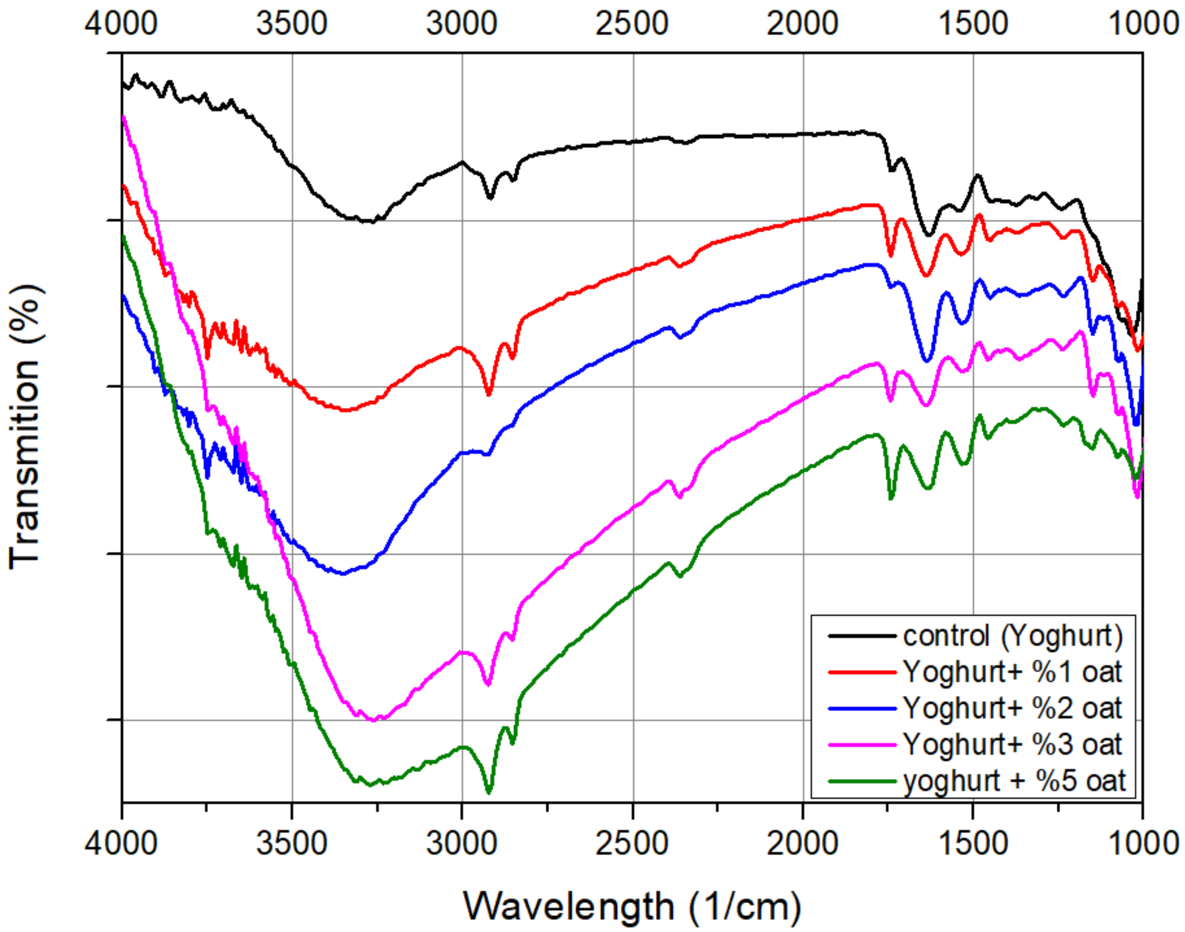

Figure 2. FTIR spectra of yogurt (control) and fortified yoghurt with (1%, 2%, 3%, and 5%) oat .

3.4 Water holding capacity determination

the oat powder addition greatly improved the water holding capacity (WHC) of the yogurt ingredients, as observed from Figure 3. WHC increased proportionately based on the oat levels added. The lowest WHC value was found for the control, while the highest WHC value was found for the yogurt added with 5% oat concentrations. This clearly reveals that the addition of oat increases the WHC of the yogurt.

This may be associated with the functional qualities of oat-based fibers in particular, such as β-glucan and insoluble polysaccharides, which interact with the protein matrix in a manner that creates a stronger gel network. The oat-based fibers have a considerable capacity for water-binding and act as a determinant in increasing viscosity in the yogurt and improving its structure, thus inhibiting whey separation (Raikos et al., 2020). The fibrous structure may act as a filler, inhibiting syneresis through retention of water in the protein and polysaccharide network.

It is obvious that increasing the concentration of oat flour results in a proportionally higher water holding capacity (WHC) because of the ability of food fibers to bond and interact with proteins as shown by the increased amount of hydrogen bonding and entanglements between the fibers and proteins at greater concentrations of oat flour (Guardiola-Márquez et al. 2020). During heating, the process of making yogurt can create similar fiber-protein interactions that lead to water retention.

Previous studies have shown that adding different types of cereal fibers like barley, rice bran or oat fiber increases water holding capacity (WHC), and therefore improves the overall texture in fermented dairy products (Xu et al., 2022). This is an important factor in the production of yogurt with consumers preferring a thicker yogurt texture.

Thus, whole oat enrichment, particularly at 3–5%, appears as an encouraging approach for upgrading the functional properties of yogurt with water retention, syneresis, and mouthfeel, simultaneously enriching it with dietary fiber .

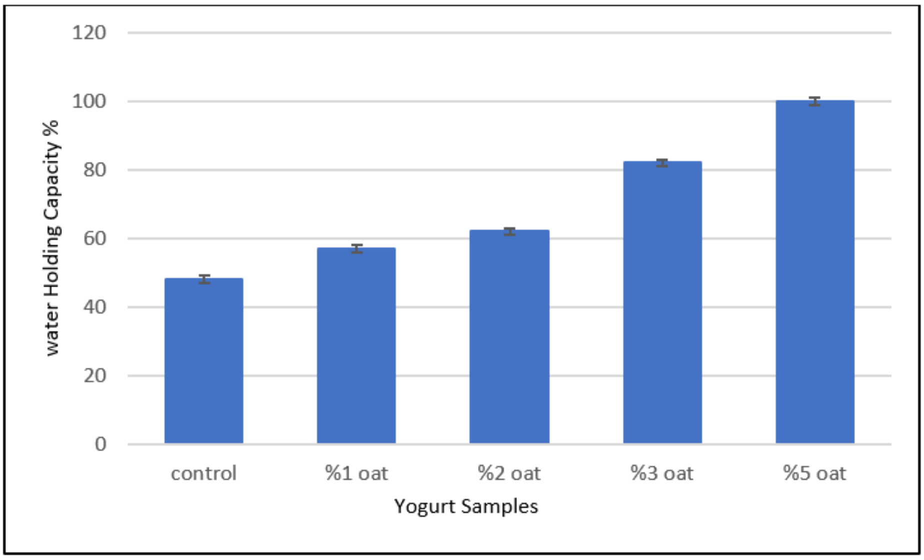

Figure 3. Water holding capacity of yogurt (control) and fortified yoghurt with (1%, 2%, 3%, and 5%) oat .

3.5 Viscosity

The viscosity curve of the yogurt samples fortified with oat powder shows a non-linear relationship between the amount of oats and the resulting viscosity (Figure 4). Although the control sample showed the highest viscosity, the 1% and 5% oat concentrations showed moderately high viscosities, while the lowest viscosity was shown by the 3% oat fortification. Thus, fortifying yogurt with whole oats affects its viscosity complexly due to the interactions between the proteins and the dietary fibers and starches present in oats.

This can be initially explained by either dilutions or disruption of the protein network structure from the insoluble oat fractions at intermediate concentrations (e.g., 3%), or it can be explained by the cumulative effects at higher concentrations (e.g., 5%) of soluble fractions like β-glucans in oat components, increasing water retention and consequently viscosity (Raikos et al., 2020.

The increased viscosity seen in the control sample might be related to the lack of particulate material, allowing for a more consistent formation of a protein gel. On the other hand, with whole oat presence, there are both soluble and insoluble components that can act as stabilizers or rupturers of the gel network depending upon their concentrations as well as hydration rates. Similar findings have also been found in fiber-supplemented dairy mixtures; here, viscosity is determined by water-binding capacity and the continuity of gels (Brückner-Gühmann et al., 2018).

These results reiterate the significance of oat concentration optimization in order to obtain favorable flow characteristics in yogurt. Although low to moderate concentration could be restrictive in terms of providing an increase in viscosity because of interference effects in the matrix, high concentration could be complementary in re-establishing it by fiber-protein interactions. Formulation studies reiterate the importance of considering the structural as well as functional contributions from whole oat in formulating fiber-supplemented fermented dairy products (Klajn et al., 2021) .

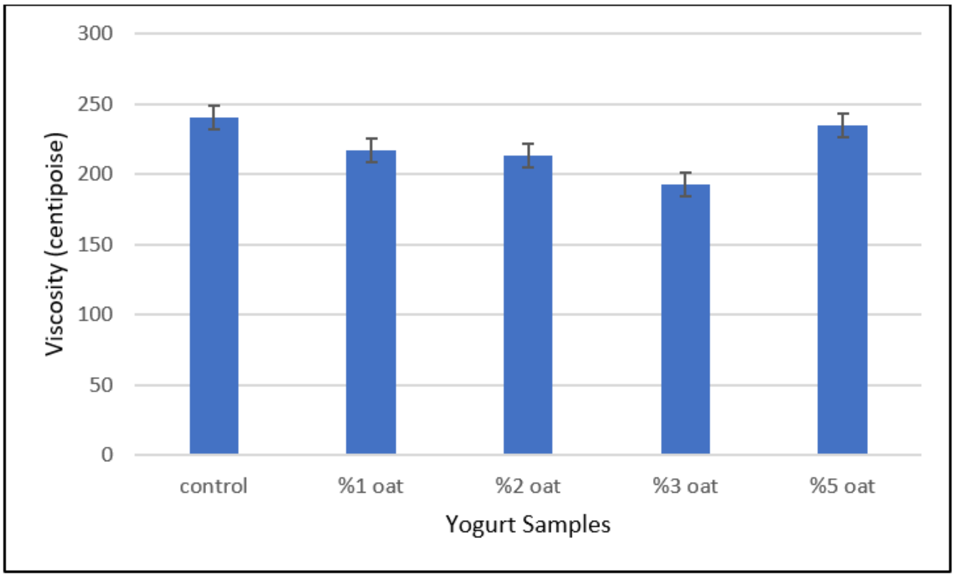

Figure 4. Viscosity (centipoise) f yogurt (control) and fortified yoghurt with (1%, 2%, 3%, and 5%) oat .

3.6 Sensory Evaluation

The sensory evaluation data provided in Table 2 clearly illustrates the effects of oat fortification in different concentrations: 1%, 2%, 3%, and 5%, on the sensory properties of yoghurt. The control sample showed the highest score in all sensory properties: appearance, body and texture, and flavor, which implies optimal consumer acceptability.

Fortification with 1% oat did not significantly affect the sensory profile, as scores were almost similar to the control. As the scores were: appearance=9/10; body and texture=25/30; flavor=55/60. Adding nutritious value to food without affecting the sensory qualities, is the indicator of adding oat.

With increasing concentrations (from 1% to 5%), appearance scores decreased on average from 9 to 7 likely due to visible changes in color, homogeneity and/or the dispersion of particulates. Body and texture scores decreased significantly (from 25 to 20). The presence of higher concentrations of oats likely disrupts smoothness and consistency in the yoghurt's structure. This observation may be related to the water absorption capacity of oats, as well as their fibrous texture may interfere with gel formation as well as mouthfeel.

The flavour was primarily the attribute that suffered the biggest impact. The scores declined from 55 (control and 1% oat) to 35 (5% oat). The significant decline in score suggests that too large of an oat content may create off-flavours or overpower the dairy flavour. Sensory fatigue and lack of familiarity with oat flavours among the panel members may also have contributed to this attribute decline. These results were in agreements with (Singh & Muthukumarappan, 2008).

Table 2. Sensory Evolution of control and fortified yoghurt with (1%, 2%, 3%, and 5%) oat .
SampleAppearance

Sample	Appearance (10)	Body and Texture (30)	Flavour (60)
Control	9	26	55
%1oat	9	25	55
%2 oat	8	25	45
%3 oat	8	20	45
%5 oat	7	20	35

4. Conclusion

The fortified yogurt with Oat powder showed improved nutritional and functional properties as well as not interfere with fermentation time. The results of laboratory testing indicated an increase in total solids, fiber, and minerals, and a slight decrease in protein due to the oat powder addition. Oat powder improved the textural characteristics of yogurt by increasing the strength and cohesiveness of the yogurt, as well as the strength of gel networks formed by protein and polysaccharides due to the presence of beta-glucans. The water holding capacity of the yogurt increased with increasing oat powder additions; therefore, syneresis was reduced and shelf life increased. The FTIR results demonstrated that polysaccharides derived from oats incorporated into the yogurt matrix, while the protein component remained intact. Additionally, viscosity test indicated a nonlinear relationship; therefore, it is very important to correctly adjust the oat powder additions to achieve optimal flow properties and acceptability to consumers.

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