DR-1846
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RESEARCH ARTICLE Asian Journal of Dairy and Food Research, Volume Issue : ()

Potential of Zinc Oxide Nanoparticle for Dietary Fortification in Yoghurt: Physicochemical, Microbiological, Rheological and Textural Analysis

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10.18805/ajdfr.DR-1846

ABSTRACT

Background: Yoghurt is a widely consumed dairy product all over the world. It has been used as an apt fortification and nutrient delivery medium in recent years.

Methods: The present study aimed to assess the suitability of zinc oxide (ZnO) nanoparticle as a potential source of fortification of zinc in yoghurt. Three different levels of ZnO nanoparticles, as well as micro-sized ZnO, were added in yoghurt. Physicochemical, sensory, microbiological, rheological and textural characteristics of yoghurt were determined during 7 days of storage at 7±1°C.

Result: Significant differences in physicochemical properties were observed in yoghurt samples during storage. All the yoghurt samples showed non-Newtonian characteristics. Zinc oxide nanoparticle added @ 75 ppm was found best for yoghurt fortification and showed advantages over fortification with conventional micro-sized ZnO. In this study, the effects of fortification of yoghurt with zinc oxide nanoparticle during storage were investigated. The FFA content of yoghurt was found to be 0.46% oleic acid and the Peroxide Value was found to be 0.32 Milli equivalent/kg fat, which was found to increase during storage. The tyrosine value at zero day was found to be 2.2 mg/g. The LAB count was 10.59 log10 CFU/g. Plastic viscosity of yoghurt was found to be 10.8.3 cP. Fortification of yoghurt with zinc oxide nanoparticle proved to be advantageous over fortification with micro-sized zinc oxide in terms of physico-chemical, microbiological, rheological and textural characteristics. Fortification of yoghurt with zinc oxide nanoparticle proved to be highly promising for zinc enrichment in the food system.

Key words: Fortification, Nanoparticle, Rheology, Yoghurt, Zinc.

INTRODUCTION

Zinc is one of the most critical micronutrients, deficiency of which often leads to several malfunctioning of the body like infant diarrhoea, compromised immune function; immature greying of hair, delayed sexual maturity and other related health issues. Deficiency of zinc has been recognized as a global problem affecting developed and developing countries (Salgueiro *et al.*, 2000). Strategic food fortification seems to be an effective solution for addressing different deficiency diseases among individuals. Yoghurt, a fermented dairy product, contains high-quality proteins and is being widely accepted by consumers all over the world (Mckinley, 2005). It could be a good vehicle for micronutrient fortification including zinc. Nanotechnology is capable of delivering different novel applications ranging from agricultural production to food processing. The nano-structured nutrients also provide more available surface area facilitating for enhanced absorption (Sirelkhatim *et al.* 2015). Hence, nanomaterials seem to be highly promising for strategic food fortifications (Santillán-Urquiza *et al.*, 2017a). The present study was aimed at exploring the use of ZnO nanoparticles as a potential alternative of micro-sized ZnO for the fortification of yoghurt to be used for personalized nutrition.

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How to cite this article: Karmakar, P., Ray, P.R., Chatterjee, P.N., Mahato, A. and Haldar, L. (2022). Potential of Zinc Oxide Nanoparticle for Dietary Fortification in Yoghurt: Physicochemical, Microbiological, Rheological and Textural Analyses. Asian Journal of Dairy and Food Research. DOI: 10.18805/ajdfr.DR-1846.

Submitted: 26-11-2021 **Accepted:** 20-06-2022 **Online:** 13-07-2022

MATERIALS AND METHODS

Collection of materials

Raw milk procured from the cows maintained at Livestock Farm Complex of West Bengal University of Animal and

Fishery Sciences, Mohanpur Campus, West Bengal, was used for the preparation of yoghurt. Yoghurt culture YoFlex Express 1.0 was (CHR Hansen Laboratory, India) was used for the preparation of yoghurt. Skim milk powder used was of "Sagar" brand, marketed by GCMMF, Anand, India. ZnO nanoparticle used for Yoghurt fortification was devised under the DBT's (Department of Biotechnology, Government of India) Programme for NE (BT/PR25311/NER/95/1127/2017) adopting environment benign colloidal chemistry route (Chatterjee *et al*., 2019).

Preparation of zinc fortified yoghurt

Yoghurt was prepared as per the methods described by Santillán-Urquiza *et al*. (2017b) with minor modification. Cow milk was first standardized to 3.5% fat, heated to 90°C for 20 minutes and then cooled down to 40°C. Lyophilized yoghurt culture was then added to the milk and stirred for 10 minutes and poured into multiple 100ml plastic containers. Both ZnO nanoparticle and micro-sized ZnO were added at a concentration of 50ppm, 75 ppm and 100 ppm respectively and stirred for 20 minutes until complete dissolution. No salts were added in the control sample. All the samples were incubated at 45°C for 5 hours. The prepared yoghurt samples were kept at 7±1°C for further use.

Physicochemical analysis

The main objective of the study was to determine the effect of the addition of various forms of zinc salts on its physicochemical properties. Yoghurt sample was analysed for fat, protein and lactose content. Analytical methodologies such as Titratable acidity, Free Fatty acid, Peroxide Value, Tyrosine value and microbiological tests were carried out to determine the effect of zinc fortification into yoghurt on its physicochemical properties. Fat in raw milk and fat, lactose and titratable acidity of yoghurt were determined by the method as described in Indian Standard (IS: SP: 18 Part XI 1981). The Protein content of yoghurt was determined using conventional micro-Kjeldahl digestion and distillation procedure as per the method described in AOAC (2000). Free fatty acid (FFA) of yoghurt was quantified using the method described in IS: 3508 (1966). Peroxide value was determined following the method given in IS: 3508 (1966) and expressed as milliequivalent of oxygen per kilogram of fat. Tyrosine value was determined by spectrophotometric method at 680nm wavelength following the method described by Hull (1947). The developed colour was measured at 680 nm in a colorimeter. A standard curve was prepared by determining the optical density at 680 nm for TCA mixtures containing 0 to 125 μg tyrosine/ml. Standard curve of tyrosine was prepared using tyrosine between 50 and 600 μL concentrations.

Microbiological analysis

Lactic acid bacteria (LAB) count of yoghurt samples was determined by using the method described by Kailasapathy *et al*. (2008) with minor modification. The calculated results were expressed as a colony-forming unit (CFU) per gm or ml by multiplying the average number of colonies with the reciprocal of the dilution factor.

Sensory evaluation

Yoghurt samples were subjected to sensory evaluation by a panel of five trained judges using 100 points composite scorecard suggested by Ranganadham and Gupta (1987) with modifications in score value. Score value for flavour, body and texture and colour were fixed at 50, 35 and 15 respectively.

Rheological analysis

Rheological properties of yoghurt was measured by using a rotational viscometer (DV-III Ultra, Brookfield, Middleboro, MA, USA) following the method described by Santillán-Urquiza *et al*. (2017b). The strain rate was applied from 10-85 s^{-1} to the samples to get the apparent viscosity values. Shear stresses (τ) were determined at the corresponding shear rates (γ) obtained by using 5, 10, 20, 30, 50, 60, 70, 80, 90 and 100 rpm at 20°C. The experimental data were fitted in a Herschel- Bulkley model. Yield stress (τ_0), flow behaviour index (n) and consistency coefficient (k) of these mathematical models were used to characterize the flow behaviour of yoghurt samples.

Textural analysis

Hardness and cohesiveness of the yoghurt samples were determined using a texture analyzer TAXT2i (Stable Microsystems, Surrey, UK) following the method described by Santillán-Urquiza *et al.* (2017b). All measurements were carried out at 20°C on 0, 3rd, 5th and 7th day. A minimum of three samples per replicate was run.

Statistical analysis

In the present study, a completely randomized design (CRD) has been adopted. To evaluate the efficacy of different sources of Zn, seven treatments namely, T1-Micro-sized ZnO with 50 ppm, T2- Micro-sized ZnO with 75 ppm, T3-Micro-sized ZnO with 100 ppm, T4- Nano ZnO with 50 ppm, T5-Nano ZnO with 75 ppm, T6- Nano ZnO with 100 ppm and T7- No ZnO were considered each having with 12 replications (4×3). The influence of the above seven treatments on yoghurt quality was evaluated at four different days (0, 3rd, 5th, 7th day).

In next phase of our study to compare the optimized dose (75 ppm) of different Zn sources (micro-sized ZnO and ZnO nanoparticles) in respect to untreated control (without adding Zn) the same model has been used. One-way analysis of variance (ANOVA) was performed using SPSS software (SPSS 20.0, SPSS Inc., Chicago), Duncan's multiple range tests (DMRT) was also employed to find out significantly different treatment means at 5% level of significance.

RESULTS AND DISCUSSION

The present investigation is an attempt to find out the effect of the addition of zinc on physicochemical, microbial,

Table 1: Physicochemical properties of yoghurt fortified with different levels of micro-sized ZnO and ZnO nanoparticle.

Parameter	Day	Control	50 ppm micro ZnO	75 ppm micro ZnO	100 ppm micro ZnO	50 ppm nano ZnO	75 ppm nano ZnO	100 ppm nano ZnO
FFA (% oleic acid)	0	0.47 ± 0.02^{D}	0.46 ± 0.01^{D}	0.46 ± 0.01^{D}	0.46 ± 0.01^{D}	0.46 ± 0.01^{D}	0.46 ± 0.02^{D}	0.46 ± 0.01^{D}
	3	0.54 ± 0.01^{Ca}	0.53 ± 0.01^{Ca}	0.52 ± 0.01^{Cb}	0.52 ± 0.01^{Cb}	0.51 ± 0.012^{Cc}	0.51 ± 0.01^{Cc}	0.51 ± 0.01^{Cc}
	5	0.71 ± 0.01^{Ba}	0.71 ± 0.01^{Ba}	0.68 ± 0.02^{Bb}	0.65 ± 0.01^{Bc}	0.71 ± 0.006^{Ba}	0.66 ± 0.01^{Bc}	0.61 ± 0.01^{Bd}
	7	0.82 ± 0.01^{Aa}	0.80 ± 0.01^{Ab}	0.77 ± 0.01^{Ac}	0.77 ± 0.01^{Ac}	0.80 ± 0.016^{Ab}	0.72 ± 0.01^{Ad}	0.70 ± 0.01^{Ad}
Peroxide value (Milli equivalent/kg fat)	0	0.32 ± 0.08^{D}	0.31 ± 0.05^{D}	0.31 ± 0.01^{D}	0.31 ± 0.05^{D}	0.32 ± 0.08^{D}	0.32 ± 0.08^{D}	0.32 ± 0.08^{D}
	3	0.56 ± 0.05^{Ca}	0.53 ± 0.08^{Ca}	0.46 ± 0.015^{Cb}	0.42 ± 0.012^{Cb}	0.51 ± 0.03^{Cb}	0.46 ± 0.01^{Cc}	0.41 ± 0.05^{Cd}
	5	0.75 ± 0.012^{Ba}	0.72 ± 0.08^{Bb}	0.65 ± 0.05^{Bc}	0.61 ± 0.05^{Bd}	0.70 ± 0.05^{Bb}	0.61 ± 0.01^{Bc}	0.58 ± 0.05^{Bd}
	7	0.93 ± 0.05^{Aa}	0.91 ± 0.05^{Aa}	0.84 ± 0.015^{Ab}	0.81 ± 0.05^{Ac}	0.88 ± 0.05^{Ab}	0.78 ± 0.02^{Ac}	0.75 ± 0.05^{Ad}
Tyrosine value (mg/g)	0	2.30 ± 0.05^{D}	2.23 ± 0.08^{D}	2.20 ± 0.11^{C}	2.20 ± 0.05^{C}	2.20 ± 0.05^{D}	2.20 ± 0.05^{D}	2.20 ± 0.05^{D}
	3	2.80 ± 0.05^{Ca}	2.70 ± 0.05^{Ca}	2.30 ± 0.05^{Cb}	2.30 ± 0.05^{Cb}	2.70 ± 0.05^{Ca}	2.40 ± 0.05^{Cb}	2.40 ± 0.05^{Cb}
	5	3.80 ± 0.05^{Ba}	3.80 ± 0.05^{Ba}	3.23 ± 0.08^{Bb}	3.23 ± 0.08^{Bb}	3.30 ± 0.05^{Bb}	2.90 ± 0.05^{Bc}	2.90 ± 0.05^{Bc}
	7	4.80 ± 0.05^{Aa}	4.70 ± 0.05^{Aa}	4.17 ± 0.03^{Ab}	4.17 ± 0.03^{Ab}	4.40 ± 0.05^{Ab}	3.90 ± 0.05^{Ac}	3.87 ± 0.03^{Ac}
Sensory scores of 0 day of yoghurt fortified with different levels of micro-sized ZnO and ZnO nanoparticle								
Flavour	0	45.60 ± 0.67^{a}	45.20 ± 0.58^{a}	45.40 ± 0.51^{a}	39.00 ± 0.44^{b}	45.20 ± 0.58^{a}	45.40 ± 0.51^{a}	39.00 ± 0.44^{b}
Body and texture		27.20 ± 0.86^{a}	29.60 ± 0.67^{b}	34.20 ± 0.37^{c}	34.20 ± 0.37^{c}	29.60 ± 0.67^{b}	34.20 ± 0.37^{c}	34.20 ± 0.37^{c}
Colour		14.60±0.24	14.20±0.37	14.60±0.24	14.60±0.24	14.20±0.37	14.60±0.245	14.60±0.24

Values are the mean of three replicates in four batches (n=12).

Means bearing different superscripts within a column (A, B, C and D) and within a row (a, b, c and d) differ significantly ($p<0.05$).

rheological, textural and sensory qualities of yoghurt made from cow milk having 3.5% fat, 3.7% protein and 4.7% lactose and 2.5% ash. The yoghurt samples prepared were found to have 3.5, 3.7, 4.9 and 2.5 per cent of fat, protein, lactose and ash respectively with the acidity of 0.9% in terms of lactic acid.

Physicochemical analysis

Free fatty acid (FFA) content of yoghurt

The FFA content of yoghurt fortified with micro-sized ZnO (50 ppm, 75 ppm and 100 ppm w/v) and ZnO nanoparticles (50 ppm, 75 ppm and 100 ppm w/v) are presented in Table 1. The FFA content of yoghurt was found to be 0.46% oleic acid which was found to increase during storage. Significant deterioration in oxidative stability was observed in the control sample (without Zn fortification) with the progression of storage. Samples containing ZnO nanoparticles @ 50 ppm, 75 ppm and 100 ppm showed lower FFA content compared to other samples with the progression of storage depicting lower fat hydrolysis. Rao and Reddy (1984) reported that fermentation of whole milk done by adding *Lactobacillus acidophilus, Lactobacillus bulgaricus* and *Streptococcus thermophilus* showed a significant increase in the percentage of oleic acid along with saturated fatty acids. Yadav *et al.* (2007) observed that probiotic.

Peroxide value (PV) of yoghurt

Peroxide value is a measure of the primary oxidation of the product. The PV of yoghurt fortified with different micro-sized and nano-structured ZnO has been presented in Table 1. The peroxide value was found to be 0.32 Milli equivalent/kg fat. The PV of all samples was found to increase with the increasing period of storage. The PV of the control sample exerted a significant deterioration over the period under study (day 0 to day 7). Micro-sized ZnO fortification favoured the storage quality of yoghurt as revealed by lowered peroxide value. However, the samples fortified with ZnO nanoparticles showed a lowered PV value as compared to control or micro-sized ZnO fortified samples from third day of storage. A dose-dependent increase in PV value was observed in fortified milk samples and the best protection has been achieved at 100 ppm ZnO nanoparticles fortified samples. Nkhata *et al.* (2015) reported a lowered PV in yoghurt fortified with ZnO nanoparticles.

Tyrosine value of yoghurt

Tyrosine value of the samples determines the proteolysis in a product. The tyrosine value of yoghurt fortified with different doses of micro-sized ZnO and ZnO nanoparticles are presented in Table 1. The tyrosine value at zero day was found to be 2.2 mg/g. The tyrosine value of the untreated control sample found to be changed significantly over the period. All the yoghurt samples containing microsized ZnO and ZnO nanoparticles showed a significant change in tyrosine value with the progression of storage but with lesser intensity.

Sensory evaluation

The sensory scores of yoghurts fortified with micro-sized ZnO (50 ppm, 75 ppm and 100 ppm w/v) and ZnO nanoparticle (50 ppm, 75 ppm and 100 ppm w/v) are presented in Table 1. The table shows that there were significant differences ($p<0.05$) in sensory attributes between samples. Sample containing 75 ppm ZnO and 75 ppm ZnO nanoparticle was best in sensory attributes among the different zinc salt concentrations. All other samples with different salt concentrations were lower in flavour or body and texture. The samples with 75 ppm ZnO and 75 ppm ZnO nanoparticles showed overall best results. The present findings agreed with the earlier observations of Seleet *et al.* (2011) where the sensory scores of zinc-fortified fermented milk product revealed better sensory properties during 10 days of storage.

Lactic acid bacteria (LAB) count of yoghurt

The lactic acid bacteria count of the yoghurt samples during storage are presented in Table 2. The LAB count was 10.59 log10 CFU/g. No significant reduction in LAB count was observed in ZnO fortified yoghurt samples as compared to control sample during storage at 7±1°C. It can be concluded that fortification of yoghurt with ZnO nano particles did not affect the growth of lactic acid bacteria during storage. Sirelkhatim *et al.* (2015) also reported that the cytoplasmic membrane with multilayer peptidoglycan polymer and a thicker cell wall (20-80nm) might have prevented gram positive bacteria such as *Lactobacillus spp*. from the antimicrobial effect of ZnO nano particle.

Rheological properties of yoghurt

Viscosity and shear stress of the yoghurt samples are given in the viscosity curve (Fig 1). The relationship between shear rate, shear stress and viscosity of the yoghurt samples are presented in Table 3 and 4. The viscosity curve shows that all samples including control were of plastic nature because the shear stress values did not start at zero. All the yoghurt samples showed non-Newtonian behaviour. Ramirez and Velez-Ruiz (2013) reported the non-Newtonian behaviour of yoghurt added with different ingredients. The shear stress and strain rate values were fitted in the Herschel Bulkley model with closeness to Casson-Plastic type rheological model as determined by a high coefficient of determination

Table 2: Lactic count (log10 CFU/g) of conatrol and fortified yoghurt during storage.

Days	Control	75 ppm ZnO	75 ppm ZnO nanoparticles
Day 0	$10.59±0.01^{Da}$	$10.59±0.01^{Da}$	$10.59±0.01^{Da}$
Day 3	$10.59±0.01^{Db}$	$10.66±0.01^{Ca}$	$10.66±0.01^{Ca}$
Day 5	$10.69±0.01^{Bb}$	$10.72±0.01^{Ba}$	$10.72±0.01^{Ba}$
Day 7	$10.83±0.01^{Aa}$	$10.85±0.01^{Aa}$	$10.84±0.01^{Aa}$

Mean values (n=12) bearing the same superscripts in a column (A, B, C, D) and row (a, b, c, d) did not differ significantly ($p<0.05$).

Table 3: Relationship between shear rate and shear stress.

Shear rate (s^{-1})	Shear stress (dyne/cm^2)		
	Control	75 ppm ZnO	75 ppm ZnO nanoparticles
10.00	95.20	88.40	125.80
20.00	121.55	108.80	151.30
30.00	139.40	124.95	165.75
40.00	153.85	137.70	183.60
50.00	163.20	146.20	182.75
60.00	170.00	155.55	198.05
70.00	180.20	161.50	198.05
80.00	184.45	166.60	208.25
85.00	186.15	169.15	210.80
85.00	185.30	166.60	201.45

Values are the mean of three replicates in four batches (n=12).

Table 4: Relationship between shear rate and viscosity.

Shear rate (s^{-1})	Viscosity (cP) (Control)	Viscosity (cP) (75 ppm ZnO)	Viscosity (cP) (75 ppm ZnO nanoparticles)
10.00	952.00	884.00	1258.00
20.00	607.75	544.00	756.50
30.00	464.67	416.50	552.50
40.00	384.63	344.25	459.00
50.00	326.40	292.40	365.50
60.00	283.33	259.25	330.08
70.00	257.43	230.71	282.93
80.00	230.56	208.25	260.31
85.00	219.00	199.00	248.00
85.00	218.00	196.00	237.00

Values are the mean of three replicates in four batches (n=12).

(R^2> 0.98). The rheological parameters of the yoghurt samples are presented in Table 5. Plastic viscosity of yoghurt was found to be 10.8.3 cP. The yoghurt fortified with ZnO nanoparticle showed higher yield stress and viscosity as indicated by higher consistency coefficient values. In the case of yoghurt fortified with ZnO nanoparticle significant increase in the consistency coefficient was observed which can be associated with the interaction of ZnO nanoparticle with casein micelle and more specific binding with colloidal calcium phosphate, which enhances the consistency. This indicates a greater interaction which may be associated with large surface area and size of the ZnO nanoparticles. All the yoghurt samples showed a plastic-shear thinning behaviour with flow index values lower than 1. The flow behaviour index varies from 0.2295 to 0.31 for the Herschel-Bulkley model, showing significant differences (p>0.05) between ZnO nanoparticle with micro-sized ZnO fortified samples and control (Table 5). The lower flow behaviour index was associated with the higher consistency coefficient of the ZnO nanoparticle fortified sample. Similar observations were reported by Santillán-Urquiza *et al.* (2017b) in yoghurt fortified with nano and micro- sized zinc salts.

Textural properties of yoghurt

As presented in Table 6, firmness was found higher in yoghurt samples fortified with ZnO nanoparticle which reflects the formation of a strong gel structure with ZnO nanoparticle as compared to the others. The initial firmness of micro-sized ZnO and ZnO nanoparticle fortified yoghurt was found to be 0.73 and 0.65 N. The difference might be attributed to the better interaction of ZnO nanoparticles with protein matrix of the yoghurt because of their larger surface area. Santillán-Urquiza *et al.* (2017a) reported a similar observation where he found higher firmness in Zn nanoparticle fortified yoghurt.

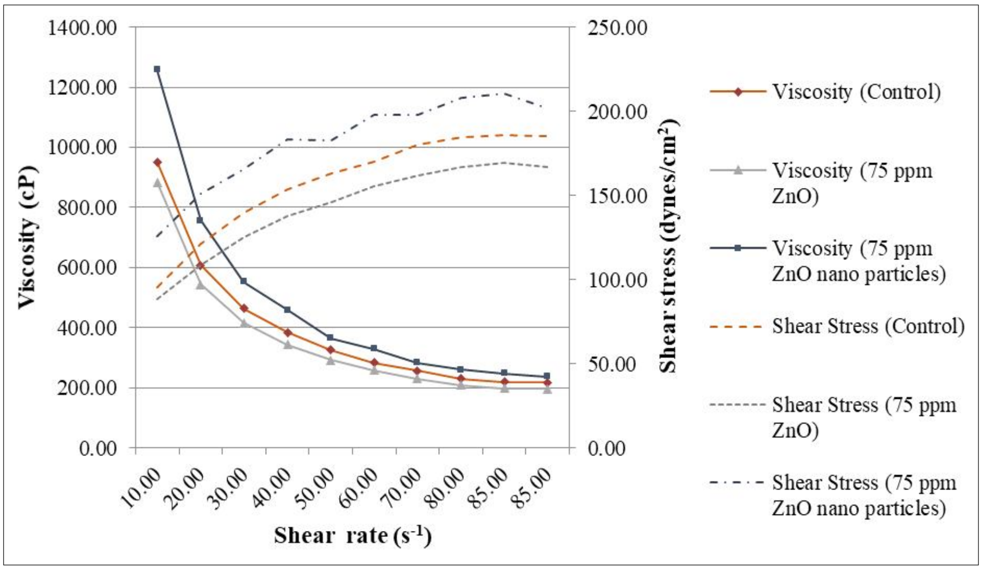

Fig 1: Graphical representation of viscosity and shear stress of yoghurt fortified with 75 ppm micro-sized Zinc oxide and 75 ppm zinc oxide nanoparticles.

Table 5: Rheological parameters of control and fortified Yoghurt.

Rheological parameters	Control	75 ppm ZnO	75 ppm ZnO nanoparticles
Yield Stress (Pa)	10.05±0.01^{A}	9.09±0.02^{A}	13.23±0.01^{B}
Plastic viscosity (cP)	108.3±0.02^{A}	97.4±0.01^{B}	94.9±001^{B}
Consistency coefficient (Pa-s^{n})	4.4259±0.0001^{A}	4.7791±0.0001^{A}	7.5615±0.0002^{B}
Flow behaviour index (n)	0.3034±0.0001^{A}	0.31±0.0001^{A}	0.2295±0.0002^{B}

Values are the mean of three replicates in four batches (n=12).

Mean values bearing different superscript with in a row (A and B) differ significantly (p<0.05).

Table 6: Textural properties of yoghurt during storage.

Sample	Time (Days)	Firmness	Cohesiveness
Control	0	0.63±0.02^{aC}	-0.44±0.01^{aC}
	3	0.61±0.01^{a}	-0.43±0.02^{a}
	5	0.60±0.01^{a}	-0.41±0.01^{b}
	7	0.57±0.02^{b}	-0.39±0.01^{b}
ZnO nano	0	0.73±0.02^{aB}	-0.53±0.02^{aB}
particle	3	0.72±0.01^{a}	-0.51±0.01^{a}
	5	0.70±0.01^{a}	-0.48±0.01^{b}
	7	0.68±0.01^{b}	-0.46±0.01^{b}
Micro-sized	0	0.65±0.01^{aC}	-0.48±0.01^{aD}
ZnO	3	0.64±0.02^{a}	-0.46±0.01^{a}
	5	0.62±0.01^{b}	-0.43±0.01^{b}
	7	0.60±0.01^{b}	-0.40±0.01^{c}

Values are the mean of three replicates in four batches (n=12).

Values with different superscripts within a column are significantly different (p<0.05).

Lower case letters signify differences during storage. Capital letters signify differences between samples.

The value of cohesiveness was higher in all fortified samples as compared to the control yoghurt sample. Firmness and cohesiveness of all yoghurt samples were determined on 0, 3rd, 5th and 7th day of storage. Significant decrease in firmness and cohesiveness with increase in storage period was found for all samples.

CONCLUSION

The present study led to the preparation of yoghurt fortified with ZnO nanoparticle as potential zinc enriched food prepared for human consumption which can combat the zinc deficiency associated problems. The FFA content of yoghurt was found to be 0.46% oleic acid and the Peroxide Value was found to be 0.32 Milli equivalent/kg fat, which was found to increase during storage. The tyrosine value at zero day was found to be 2.2 mg/g. The LAB count was 10.59 log10 CFU/g. Plastic viscosity of yoghurt was found to be 10.8.3 cP. Yoghurt fortified with ZnO nanoparticles was found best during storage as compared to yoghurt fortified with micro-sized ZnO and unfortified yoghurt. ZnO nanoparticles fortified yoghurt samples exhibited the lowest increase in FFA throughout the storage study. Peroxide value increases during storage period, but comparatively lower peroxide value was observed in yoghurt fortified with ZnO nanoparticles. The lowest increase in tyrosine value was also observed in yoghurt fortified with ZnO nanoparticles. However, fortification with ZnO nanoparticles did not affect the growth of lactic acid bacteria during storage. The rheological analysis showed the nature of yoghurt a Casson-plastic having non- Newtonian behaviour. Better consistency coefficient, flow behaviour index and firmness were observed in ZnO nanoparticle fortified yoghurt samples. ZnO nanoparticles fortified yoghurt samples showed better physicochemical and microbiological characteristics that determined an improvement in the final quality of the yoghurt. Therefore, fortification of yoghurt with ZnO nanoparticle @ 75 ppm seems to be highly promising for zinc enrichment in the food system.

ACKNOWLEDGEMENT

For conducting the present study necessary resources has been provided by Department of Biotechnology, Govt. of India. The authors are thankful to Dr. Sougata Sarkar (Asst. Professor, Ramakrishna Vivekananda Centenary College, Rahara, West Bengal) for his guidance to characterize the nanomaterials. The assistance provided by Dr. B.N. Mandal (Senior Scientist, Indian Agricultural Statistics Research Institute, ICAR, New Delhi) is also being acknowledged.

Conflict of interests

The authors declare that they have no conflict of interest.

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