Effect of zinc fortification on Cheddar cheese quality

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ABSTRACT

Zinc-fortified Cheddar cheese containing 228 mg of zinc/kg of cheese was manufactured from milk that had 16 mg/kg food-grade zinc sulfate added. Cheeses were aged for 2 mo. Culture activity during cheese making and ripening, and compositional, chemical, texture, and sensory characteristics were compared with control cheese with no zinc sulfate added to the cheese milk. Compositional analysis included fat, protein, ash, moisture, zinc, and calcium determinations. The thiobarbituric acid (TBA) assay was conducted to determine lipid oxidation during aging. Texture was analyzed by a texture analyzer. An untrained consumer panel of 60 subjects evaluated the cheeses for hardness, off-flavors, appearance, and overall preference using a 9-point hedonic scale. Almost 100% of the zinc added to cheese milk was recovered in the zinc-fortified cheese. Zinc-fortified Cheddar cheese had 5 times more zinc compared with control cheese. Zinc-fortified cheese had higher protein and slightly higher fat and ash contents, whereas moisture was similar for both cheeses. Zinc fortification did not affect culture activity during cheese making or during the 2-mo aging period. The TBA value of control cheese was higher than that of zinc-fortified cheese at the end of ripening. Although zinc-fortified cheese was harder as determined by the texture analyzer, the untrained consumer panel did not detect differences in the sensory attributes and overall quality of the cheeses. Fortification of 16 mg/kg zinc sulfate in cheese milk is a suitable approach to fortifying Cheddar cheese without changing the quality of Cheddar cheese.

Key words: zinc sulfate, fortification, Cheddar cheese, cheese

INTRODUCTION

Zinc is an essential mineral that is naturally present in most foods, and it may be added to others.

Zinc is also readily available as a dietary supplement. Today, many over-the-counter cold remedies and numerous cold lozenges contain zinc and it is involved in numerous important aspects of cellular metabolism. It is required for the catalytic activity of more than 100 enzymes (Shrimpton and Shankar, 2008; Qin et al., 2009; Saper and Rash, 2009) and has an important role in immune function, protein synthesis, wound healing, DNA synthesis, and cell division (Hunt and Nielsen, 2009; Walongo, 2009). Zinc is needed for normal growth and development during pregnancy as well as during childhood and adolescence (Simmer and Thompson, 1985). It is required for the sense of taste and smell (Prasad et al., 1997). Because the body does not have the capacity to store zinc, a daily intake of zinc is required for normal health and maintenance (Rink and Gabriel, 2000; Salgueiro et al., 2000b).

The current recommended dietary allowance (RDA) for zinc in the United States is 11 mg for men and 8 mg for women per day as per Food and Nutrition Board and Institute of Medicine (2001). These values are higher for pregnant and lactating women, at 12 and 13 mg per day, respectively (Jeejeebhoy, 2009). The World Health Organization and Food and Agriculture Organization, however, provide RDA values according to diets differing in zinc bioavailability. For a diet with high zinc bioavailability (i.e., diets high in meat), 3.0 to 4.2 mg/d is recommended. For a diet with moderate bioavailability, 4.9 to 7.0 mg/d, and for a diet with low bioavailability (i.e., vegetarian diets), 9.8 to 14.0 mg/d are recommended (Shrimpton and Shankar, 2008). Approximately 2 billion people in the world and 12% of Americans are estimated to be at risk of inadequate zinc intake (Song et al., 2010).

People with gastrointestinal disorders, vegetarians, pregnant and lactating women (particularly those starting pregnancy with marginal zinc status), older infants who are exclusively breast fed, those with sickle cell disease, and alcoholics are also considered at risk of zinc inadequacy. Bioavailability of zinc from vegetarian diets is low because vegetarians do not eat meat and meat is high in bioavailable zinc. Furthermore, vegetarians typically eat high levels of legumes and whole grains, which contain phytates that bind zinc and inhibit its absorption (ADA, 2003; Hunt, 2003).

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Table 1. Zinc contents of some dairy products

Dairy product	Zinc content (mg/100 g)
Cream cheese ¹	1.4
Mozzarella ¹	3.1
Ricotta ¹	1.1
Yogurt ¹	0.9
Cheddar ¹	3.1
Chocolate milkshake ¹	0.4
Milk ²	
Cow	0.3
Goat	0.3
Sheep	0.5–0.7

¹USDA (2010).²Raynal-Ljutovac et al. (2008).

A wide variety of foods in the US diet, including dairy foods, contain zinc at varying levels (Ma and Betts, 2000; Shrimpton and Shankar, 2008). Table 1 provides the zinc contents of some common dairy foods. Cheese is increasingly becoming an important part of the American diet. Thus, fortification of cheese with zinc would provide the groups at risk of zinc inadequacy, including vegetarians who do not consume meat but still consume dairy products, with an additional good food source high in zinc.

Food fortification has been commonly used to improve mineral and vitamin status and to eradicate deficiencies. However, the food that is to be fortified and the nutrient selected for fortification have to be chosen carefully. Furthermore, nutrients used for fortification should be stable during storage of the food (Drago and Valencia, 2002; Salgueiro et al., 2002). Five zinc salts have obtained GRAS (Generally Recognized As Safe) status from the US Food and Drug Administration: zinc sulfate, zinc chloride, zinc gluconate, zinc oxide, and zinc stearate (Salgueiro et al., 2002). Among these, zinc oxide and zinc sulfate are most commonly used (Hotz et al., 2005); they are both relatively inexpensive. However, zinc oxide is less readily soluble in liquid foods and is not as readily absorbed (Salgueiro et al., 2000a, 2002). Zinc sulfate has higher bioavailability but has been reported to affect flavor (Salgueiro et al., 2000a, 2002) and modify the perception of sweetness (Keast et al., 2004; Čmejlová et al., 2009). Our preliminary studies showed that zinc sulfate was more readily incorporated into cheese milk than other salts and thus was selected for remainder of our studies.

The intent of this study was to determine if zinc sulfate could be incorporated into cheese milk to manufacture zinc-fortified cheese without affecting the quality and sensory attributes of Cheddar cheese. This would provide groups at risk of zinc inadequacy, the elderly, and vegetarians who do not consume meat but still

consume dairy products with an additional food source that is high in zinc.

MATERIALS AND METHODS

Starter Culture Growth and Activity

Reconstituted skim milk (12%) containing 16 mg/kg of food-grade zinc sulfate (Barrington Nutritionals, Harrison, NY) was sterilized (121°C, 5 min). Zinc sulfate was omitted in the control treatment. Each flask was cooled to 35°C and inoculated with 1% (wt/wt) commercial Cheddar cheese culture, *Lactococcus lactis* ssp. *lactis*, and *Lactococcus lactis* ssp. *cremoris* (DVS 2003, Chr. Hansen, Milwaukee, WI) and incubated at 35°C for 6 h. Growth of lactic acid bacteria was determined by sampling at 1-h intervals and plating on de Man, Rogosa, and Sharpe (MRS) agar (Sigma-Aldrich, St. Louis, MO). Plates were incubated at 35°C, 48h under aerobic conditions. Titratable acidity (TA) and pH were monitored at 30-min intervals.

Cheddar Cheese Manufacturing

Cheddar cheese was manufactured at Michigan State University Dairy Plant. Raw cow milk (average composition: 3.68% fat, 3.09% protein, 8.82% SNF for replicate 1; and 3.62% fat, 2.94% protein, 8.62% SNF for replicate 2) was HTST pasteurized (72°C, 16 s). The milk was cooled to 32°C and was divided into 2 vats containing 115 kg of milk each. One vat had 16 mg/kg food grade zinc sulfate (Barrington Nutritionals, Harrison, NY) added; the control vat had no zinc sulfate. One percent starter culture (DVS 2003, Chr. Hansen, Milwaukee, WI) was added to each vat while stirring. Both vats were incubated at 32°C for 30 min. Next, annatto coloring (4 mL) was added to each vat and stirred, and 7 mL of rennet (Chy-Max, Chr. Hansen) diluted (40× with water) was added and stirred. Vat contents were allowed to coagulate (30 min). When adequate firmness was reached, the curd was cut using wire knives. The cut curd was allowed to heal and was slowly cooked to 38°C. At the end of cooking, the whey was drained, and the curd was matted and cut into rectangular blocks and then flipped every 15 min. Titratable acidity was monitored during the cheddaring process. The curd was milled when the TA of the curds reached 0.62%. The milled curd was salted (0.25%). Salted curd was transferred into cheesecloth-lined cheese hoops and pressed overnight at 276 kPa. Both cheeses were vacuum-sealed in plastic bags and stored at 8°C and 80% relative humidity for 8 wk. Cheese-making trials were repeated 2 times.

Compositional Analysis

Both zinc-fortified and control cheeses were analyzed for protein, fat, moisture, ash, and % TA. Moisture, ash, and % TA were analyzed according to AOAC (2000). Briefly, for moisture determination, 2 g of shredded cheese samples were weighed onto predried aluminum dishes, and the samples were then dried at $130 \pm 1^\circ\text{C}$ until a constant weight was reached (~ 1.25 h). For ash determination, 5-g shredded cheese samples were weighed into pretreated ashing crucibles and placed in a muffle furnace at $530 \pm 3^\circ\text{C}$ for 18 h. For TA determination, 10 g of sample was blended with 105 mL of distilled water at 40°C and filtered through Whatman No. 1 paper. Two drops of phenolphthalein were added to 25 mL of filtrate and the sample was titrated with standardized 0.1 *N* NaOH. Fat content of the cheeses was determined according to the Babcock method (Marshall, 1992). Protein was determined using a protein analyzer (Leco FP 2000, Leco Corp., St. Joseph, MI). All analyses were carried out in duplicate except for protein analysis, which was done in triplicate.

Zinc and Calcium Analysis

Cheese (0.4 ± 0.1 g), whey (5 ± 0.1 g), and 0.4 ± 0.1 g standard samples (for zinc, bovine liver; for calcium, peach leaves) were initially treated with nitric acid overnight and further digested using a microwave oven (600 W, 160°C , 1,310 kPa) at a ramp time of 30 min and a hold time of 10 min (MARS 5, CEM Corp., Matthews, NC). Two milliliters of 8% H_2O_2 was added to all samples to stop the ashing process. Zinc and calcium contents of cheese and zinc content of whey samples were determined by atomic absorption spectrophotometer (Unicam SOLAAR 989, Thermo Elemental Corp., Franklin, MA) at 213.9 and 422.7 nm, respectively, and calculated based on standard curves. For preparation of the standard curve for zinc analysis, 0.05, 0.10, 0.20, 0.30, and 0.40 mg/kg Zn concentrations were prepared in 25-mL volumetric flasks with nitric acid (40%)/ H_2O_2 (8%) matrix modifier from a 100 mg/kg Zn solution. For calcium determination, a new standard curve was prepared for each sample and each standard was separately spiked with 2.5 and 5 mg/kg of Ca. 1% Lanthanum was added to each tube as an ionization suppressant to eliminate the phosphate interference in the air-acetylene flame.

Thiobarbituric Acid Assay

Although various methods exist for measuring progression of lipid oxidation, one of the most common methods involves detection of malondialdehyde (MDA), a

secondary product of lipid oxidation. Malondialdehyde is formed from decomposition of peroxides of PUFA and is associated with the development of rancidity and oxidative deterioration. One mole of MDA reacts with 2 moles of thiobarbituric acid (TBA) to give a pink condensation product, which then can be quantified at 530 nm. Five-gram cheese samples stored in vacuum-sealed plastic bags were weighed into beakers, and 1 mL of propyl gallate (0.2 mg/mL) was added to all beakers to prevent oxidation and blended with an extracting solution consisting of 10% TCA (Sigma-Aldrich) in 0.2 *M* H_3PO_4 (wt/vol; Sigma-Aldrich). The mixture was filtered through Whatman No. 1 filter paper. One of each sample set was initially spiked with 12 mL of 10 μM 1,1,3,3-tetraethoxypropane (TEP; Sigma-Aldrich) to correct for the variation that may occur due to extraction. Five milliliters of the filtrate was then mixed with 5 mL of 0.02 *M* TBA (Sigma-Aldrich) solution in 90% glacial acetic acid (Sigma-Aldrich). Loosely capped tubes were incubated in boiling water for 20 min to form a pink chromogen. Absorbance of each sample was determined at 530 nm. Concentrations of MDA were calculated according to the standard curve. A standard curve was prepared with 25 μM stock solution of TEP (a nonvolatile precursor of MDA, which is hydrolyzed to MDA). Aliquots of 0.5, 1.0, 1.5, 2.0, and 4.0 mL were transferred into tubes. Total volume was adjusted to 5 mL with TCA/ H_3PO_4 . Five milliliters of TBA was added to each tube and heated as described above to give final concentrations of 2.5, 5.0, 7.5, 10, and 20 nmol of MDA/mL, respectively, for the standard curve. Results were reported as milligrams of MDA per kilogram of cheese (Miller, 1998).

Texture (Hardness) Analysis

Hardness of cheeses was determined by food texture analyzer (FTC model TMS-Pro Texture System, model CS-2 Thin Blade Shear Compression Test Cell; Food Technology Corp., Rockville, MD). Each cheese was cut into $65 \times 60 \times 5$ -mm samples and equilibrated at 25°C for 4 h. The samples were placed in the texture analyzer; testing speed was set to 12.7 cm/min, and the distance was set to 88.8 mm for analysis. Each treatment was tested 5 times. Results were calculated and reported in Newtons (N, $\text{kg}\cdot\text{m}/\text{s}^2$).

Sensory Analysis by Consumer Panel

The sensory properties of cheese samples were assessed after 8 wk of ripening by 60 untrained panelists made up of faculty, staff, and students at Michigan State University (East Lansing) and members of the public who visited the Michigan State University Dairy

Store (East Lansing). Panelists were recruited by flyers that were posted around campus or by e-mail. Initially, panelists read an explanation of the study and gave their informed consent. The University Committee on Research Involving Human Subjects (UCRIHS, East Lansing, MI) approved the study. Approximately 25-g cheese samples were placed into 56-g plastic cups labeled with randomly selected 3-digit numbers, covered individually with a lid, and initially stored at refrigerated temperature. The samples were allowed to equilibrate to room temperature before serving to the panelists. The order of presentation was randomized across subjects to ensure that the order of the runs did not introduce bias into the results. The panelists were asked to score the cheeses by using a 9-point hedonic scale, where 1 = dislike extremely to 9 = like extremely, and 5 = neither like nor dislike. The panelists evaluated each sample for appearance, off flavor, hardness, and overall preference. Water and unsalted crackers were provided to the panelists for palate cleansing in between samples.

Statistical Analysis

Cheese making was replicated 2 times in a randomized design. Statistical software JMP 9.0 (SAS Institute Inc., Cary, NC) was used for statistical analysis of the results. One-way ANOVA was carried out to establish statistical differences between the compositional, TBA, TA values, and textural and sensory properties of control cheese compared with zinc-fortified cheese. Significance of differences was defined at $P < 0.05$.

RESULTS AND DISCUSSION

A few studies have reported on zinc fortification of dairy products such as milk and yogurt (Achanta et al., 2007; El-Behairy and Mohamed, 2010; Seleet et al., 2011). However, only a few available publications report on zinc-fortified cheeses (Gulbas and Saldamli, 2005; Abd-Rabou et al., 2010). Our study is the first on zinc fortification of Cheddar cheese; Zhang and Mahoney (1990, 1991) reported on iron-fortified Cheddar cheese. We selected 16 mg/kg for the level of zinc sulfate to be used based on our earlier work (Aquilanti et al., in press).

Effect of Zinc Fortification on Culture Growth and Activity

Our initial experiments determined whether addition of zinc sulfate (16 mg/kg) was detrimental to Cheddar cheese starter culture growth and activity. Figure 1 shows the effect of zinc sulfate addition on growth

of Cheddar cheese starter culture in 12% reconstituted skim milk over a 6-h incubation period. Figures 2 and 3 show the % TA and pH of the milk during the same incubation time. The commercial starter culture showed good growth and acidification activity in milk fortified with 16 mg/kg zinc sulfate (as much as the control treatment). A statistically significant difference in microbial count was seen only in the first hour of incubation between control and zinc-fortified skim milk treatments ($P < 0.05$). For the remainder of the experiment, the number of cells increased similarly in both treatments with increasing incubation time. The first hour of incubation is particularly significant in Cheddar cheese making because cheese milk is typically cultured up to 1 h. The TA and pH did not differ between control and zinc-fortified treatments ($P > 0.05$; Figures 2 and 3). Thus, our studies show that fortification of cheese milk with 16 mg/kg (0.24 mM) zinc sulfate had no inhibitory effect on starter culture.

Effect of Zinc Fortification on Cheddar Cheese Properties

Control and zinc-fortified cheeses were manufactured side by side in double-O vats, from the same source of milk using the same manufacturing procedure. Cheese making was replicated 2 times, and milk composition did not differ significantly between the 2 replicates ($P > 0.05$). Both cheeses reached the same final % TA before milling of the curd and salting. The % TA of both cheeses was also similar during the 2 mo of aging,

Figure 1. Effect of addition of zinc sulfate (16 mg/kg) on Cheddar cheese starter culture growth (cfu/mL) over 6 h of incubation in 12% reconstituted nonfat dry milk. SM = skim milk (control), SM-ZnS = skim milk fortified with zinc sulfate. Different letters indicate a significant difference between treatments ($P < 0.05$). Error bars indicate the SD.

Figure 2. Effect of addition of zinc sulfate (16 mg/kg) on Cheddar cheese starter culture activity as determined by titratable acidity (TA). SM = skim milk (control), SM-ZnS = skim milk fortified with zinc sulfate. No significant differences were observed; $n = 2$ for all treatments. Error bars indicate the SD.

indicating similar culture activity in both cheeses during aging (Table 2).

Compositional Analysis. Compositional analysis of the control and zinc-fortified Cheddar cheeses is shown in Table 3. Although not statistically different ($P > 0.05$), the fat and ash contents of the zinc-fortified cheese were higher and moisture content was lower compared with the control cheese. Protein content was significantly higher ($P < 0.05$) in the zinc-fortified cheeses (25.39%) compared with the control (24.62%). Results of total zinc and calcium analyses are shown in Table 4. Zinc content of the zinc-fortified cheese was slightly more than 5 times greater than that of the

Figure 3. Effect of addition of zinc sulfate (16 mg/kg) on pH of 12% reconstituted nonfat dry milk inoculated with Cheddar cheese starter culture. SM = skim milk (control), SM-ZnS = skim milk fortified with zinc sulfate. No significant differences were observed; $n = 2$ for all treatments. Error bars indicate the SD.

Table 2. Effect of zinc fortification on culture activity in Cheddar cheese during ripening, as determined by titratable acidity (%TA)¹

Ripening time (d)	Control cheese (%TA)	ZnS ² cheese (%TA)
0	0.26 ± 0.12	0.22 ± 0.09
7	0.26 ± 0.09	0.26 ± 0.03
30	0.31 ± 0.04	0.31 ± 0.04
60	0.34 ± 0.05	0.35 ± 0.02

¹ $n = 4$ for all treatments.

²Cheese fortified with zinc sulfate at 16 mg/kg.

control cheese (228.39 vs. 43.64 mg/kg). Only a minor amount of zinc was lost in the whey, and zinc added to cheese milk was concentrated about 13-fold in cheese. Calcium levels of both cheeses were similar ($P > 0.05$).

Singh and coworkers (1989b) reported that 32% of the zinc in bovine skim milk was directly bound to caseins, whereas about 63% was associated with colloidal calcium phosphate. The zinc-binding capacities of the individual caseins were α_{S1} -CN $>$ β -CN $>$ κ -CN. This was in the same order as their phosphoserine contents (8, 5, and 1 residues, respectively; Grosclaude et al., 1973; Singh et al., 1989a). Dephosphorylation of whole casein reduces the binding capacity of zinc, indicating that phosphoserine groups are the primary binding sites for zinc. Singh et al. (1989b) also suggested, however, that caseins contain zinc-binding sites other than phosphoserine residues. With the exception of BSA, whey proteins, β -LG, α -LA, and lactoferrin have little capacity to bind zinc (Singh et al., 1989b). We suggest that zinc was associated with the casein in milk supported by the minor amount of zinc lost in the whey.

The earlier reports by Singh et al. (1989a,b) support our results showing that nearly 100% of the zinc was retained in the cheese and very little or no zinc was lost in the whey. The high ash content of our zinc-fortified cheese was consistent with these results.

Although not statistically significant, the calcium level was higher in our control cheese than in the zinc-fortified cheese. We suggest that zinc may be partially displacing calcium in the casein micelle system, as reported earlier by Singh et al. (1989b). These results are consistent with results reported by Gulbas and Saldamli (2005) and Abd-Rabou et al. (2010). Addition of calcium chloride to milk moves casein from serum into micelle form. This leads to an increase in the total casein that can be measured by size exclusion chromatography upon addition of calcium chloride to milk (Carpenter and Brown, 1985). An increase in curd firming rate and final curd firmness due to more extensive crosslinking of the casein network due to calcium provides for better fat incorporation into the curd (Ustunol and Hicks, 1990). Addition of calcium

Table 3. Compositional analysis of the cheeses

Treatment	Fat (%)	Protein (%)	Ash (%)	Moisture (%)
Control cheese (no ZnS)	33.62 ± 0.53 ^a	24.62 ± 0.21 ^b	3.06 ± 0.26 ^a	36.53 ± 2.50 ^a
ZnS cheese ¹	34.37 ± 0.53 ^a	25.39 ± 0.29 ^a	3.22 ± 0.09 ^a	34.15 ± 1.50 ^a

^{a,b}Means within a column with different superscripts are significantly different ($P < 0.05$); $n = 4$ for all treatments.

¹Cheese fortified with zinc sulfate at 16 mg/kg.

chloride also influences aggregation of renneted micelles by decreasing their zeta potential (Dalglish, 1984). We hypothesize that the addition of zinc sulfate to cheese milk before clotting contributes to the divalent cation equilibria similarly to the addition of calcium. Divalent cation zinc provides for more bridging between caseins and for more crosslinking similar to calcium. The more rigid protein network that is produced then allows for better fat entrapment into the curd consistent with higher fat content of zinc-fortified cheeses in this study.

TBA. The TBA assay is commonly used as a marker for oxidative damage and to determine the freshness of foods (Shamberger et al., 1977). Zinc has been reported to inhibit free radical lipid peroxidation in biological systems (Girotti et al., 1985). Zinc protects membranes from iron-initiated lipid oxidation by occupying negatively charged sites with potential iron-binding capacity, or by serving as a free radical scavenger (Fang et al., 2002). Zinc may also act synergistically with water-soluble antioxidants to protect membranes from oxidation (Zago and Oteiza, 2001). Therefore, our intent was to determine if zinc would also inhibit lipid oxidation in a food system such as ours.

Table 5 shows the results of the TBA analysis of the control cheeses over 2 mo of aging. Although the TBA values of both cheeses increased with an increase in ripening time, zinc fortification did not influence TBA values of the zinc-fortified cheese. Values for TBA decreased slightly in both cheeses at the end of 2 mo and was significantly lower for the zinc-fortified cheeses,

suggesting further degradation of malondialdehyde or slight antioxidant protection provided by zinc. Zhang and Mahoney (1991) reported similar results with iron-fortified Cheddar cheese, where TBA values increased and then eventually decreased over ripening time. However, unlike zinc, iron is a pro-oxidant. The decrease in TBA values observed is thought to be due to the degradation or further reaction of malondialdehyde by the authors.

Sensory and Texture Analysis. It has been reported that zinc sulfate alters sensory attributes of foods (Salgueiro et al., 2000a, 2002). Thus, sensory properties of the cheeses were evaluated in this study using a consumer panel. Table 6 shows the results of the sensory analysis. Overall, although 52% of the consumer panelists preferred the zinc-fortified cheese and 48% of the panelists preferred the control cheese, these differences were not statistically significant ($P > 0.05$). Appearance, hardness, and off-flavor scores were similar between zinc-fortified and control cheeses. Our sensory results are consistent with those reported by Gulbas and Saldamli (2005) and Abd-Rabou et al. (2010), who also reported that zinc sulfate did not affect sensory attributes, contrary to earlier reports.

When hardness was measured with the texture analyzer, the hardness of zinc-fortified cheese (243.11 N) was significantly higher ($P < 0.05$) than that of the control cheese (226.02 N), a difference not detected by the untrained panelists. The greater hardness value of zinc-fortified cheese is consistent with the slightly higher protein and ash contents of these cheeses. This is consistent with other studies that have reported in-

Table 4. Total zinc and calcium contents of the cheeses manufactured and the zinc content of the corresponding whey

Treatment	Zinc (mg/kg)	Calcium (mg/kg)
Control cheese	43.64 ± 0.96 ^a	9,461 ± 1,429 ^a
ZnS cheese ¹	228.39 ± 34.85 ^b	9,193 ± 487 ^a
Control cheese whey	0.22 ± 0.10 ^a	NA ²
ZnS cheese whey	1.06 ± 0.08 ^b	NA

^{a,b}Means within a column with different superscripts are significantly different ($P < 0.05$); comparisons were only made between 2 treatments (control cheese vs. ZnS cheese, and control cheese whey vs. ZnS cheese whey); $n = 4$ for all treatments.

¹Cheese fortified with zinc sulfate at 16 mg/kg.

²Not analyzed.

Table 5. Effect of zinc fortification on lipid oxidation (expressed as mg/kg of malondialdehyde, MDA) in Cheddar cheese as determined by thiobarbituric acid assay

Ripening time (d)	Control cheese	ZnS cheese ¹
0	0.01 ± 0.00 ^a	0.03 ± 0.03 ^a
7	0.10 ± 0.07 ^a	0.10 ± 0.01 ^a
30	0.23 ± 0.02 ^a	0.28 ± 0.13 ^a
60	0.18 ± 0.05 ^a	0.10 ± 0.01 ^b

^{a,b}Means within a row with different superscripts are significantly different ($P < 0.05$); $n = 4$ for all treatments.

¹Cheese fortified with zinc sulfate at 16 mg/kg.

Table 6. Sensory attributes of Cheddar cheese fortified with zinc as determined by a consumer panel (n = 6)

Sensory attribute ¹	Control cheese	ZnS cheese ²
Hardness	6.53	5.97
Off flavor	5.87	5.68
Appearance	3.08	2.90
Overall preference	48	52

¹Hardness was evaluated on a scale of 1–9 where 9 = not hard, 5 = neither hard/nor soft, 1 = very hard; off-flavor was evaluated on a scale of 1–9 where 9 = no off flavors, 5 = moderate off flavor; 1 = strong off flavor; appearance was evaluated on a scale of 1–9 where 9 = dislike extremely, 5 = neither like/nor dislike, 1 = like extremely; and overall preference was reported as a percentage.

²Cheese fortified with zinc sulfate at 16 mg/kg.

creased hardness in cheese with increased protein and ash contents (Ustunol and Hicks, 1990).

CONCLUSIONS

Fortification of cheese milk with zinc sulfate is a suitable approach to fortifying Cheddar cheese without changes in the quality of Cheddar cheese. Zinc-fortified Cheddar cheese could be an excellent food source for replenishment of zinc levels in groups at risk of zinc deficiency. Consumption of a 28-g serving of regular Cheddar cheese provides 9 to 12% of the RDA for zinc in the US diet, whereas a 28-g serving of our zinc-fortified Cheddar cheese would provide approximately 79 and 57% of the RDA for men and women, respectively, in the United States. This should provide the elderly, groups at risk of zinc inadequacy, and vegetarians who do not consume meat but still consume dairy products with an additional food source that is high in zinc.

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