

## The Bread Paradox: Evaluating the Sodium-to-Calcium Ratio in Supermarket Packaged Breads

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### ABSTRACT

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**Background:** Dietary sodium excess and calcium deficiency represent concurrent public health challenges in Singapore, linked to hypertension and rising rates of osteoporotic fractures, respectively. Although packaged bread is a primary dietary staple and a recognized vehicle for "silent" nutrient fortification, the relative balance between sodium and calcium, quantified as the calcium-to-sodium mass ratio, remains poorly characterized in commercial formulations.

**Objective:** This cross-sectional study evaluated packaged bread products available in Singapore to determine the prevalence of mineral additives and whether the current formulations serve as effective calcium delivery systems without exceeding sodium thresholds.

**Methods:** Nutrient labels from seventy-nine Singaporean packaged breads were audited to quantify mineral additives, contents, and calcium-to-sodium mass ratios.

**Results:** Calcium fortification appeared in only 38% of the products. The mean calcium-to-sodium ratio was  $0.2 \pm 0.3$ , far below the desired target of 1.0, with 62% of the cohort falling below 0.1. Even "calcium" labeled breads failed to bridge this gap, averaging a ratio of only 0.5. Wholegrain did not significantly influence mineral concentrations or the resulting calcium-to-sodium ratios. These suboptimal ratios suggest a "calciuretic" environment in which excessive sodium intake likely triggers urinary calcium loss, thereby neutralizing the benefits of fortification.

**Conclusion:** While bread remains a viable vehicle for calcium fortification, its efficacy is currently stifled by metabolic antagonism. To transform bread into a genuinely osteoprotective food, future formulations must prioritize sodium reduction alongside optimized calcium delivery.

**KEY WORDS:** Calcium, Calcium-to-Sodium Mass Ratio, Food Fortification, Hypercalciuria, Packaged Bread, Sodium

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### 1. INTRODUCTION

High dietary sodium intake is a global public health concern, primarily because of its established causal link to systemic hypertension and subsequent vascular morbidity and mortality, including stroke and coronary heart disease (Health Promotion Board Singapore, 2024a). The World Health Organization (WHO) advocates for a maximum consumption of 2,000 mg per day, targeting a substantial 30% reduction in population mean sodium intake by 2025 (World Health Organization, 2025; Health Promotion Board Singapore, 2022a). Many nations, including Singapore, report average sodium intakes significantly exceeding this stringent recommended limit, necessitating targeted public health interventions (Health Promotion Board Singapore, 2022).

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Osteoporosis presents a significant and increasing public health burden in Singapore, largely driven by its rapidly aging demographic and high rates of inadequate calcium intake (Chandran & Mitchell, 2021). Epidemiologically, the incidence of osteoporotic hip fractures has dramatically increased over the past decades, showing up to a five-fold rise in women over the age of 50. These result in substantial morbidity, mortality, and a high economic cost, estimated at S\$183.5 million in 2017 (Chandran *et al.*, 2019; Koh *et al.*, 2001). National nutrition survey indicates that approximately half of the older adults aged over 60 years fail to meet the Recommended Daily Allowance (RDA) for calcium, with average population intakes falling short of the 1,000 mg guideline (Health Promotion Board Singapore, 2022).<sup>3</sup> Low dietary calcium intake is a probable contributing factor to the high prevalence of osteoporosis (Chandran & Mitchell, 2021).<sup>4</sup> Food fortification, specifically utilizing widely consumed staple foods, is recognized as a highly cost-effective strategy to address this nutritional gap.

Bread is a significant staple food within the diverse Singaporean diet, contributing to daily caloric and macronutrient intake alongside traditional sources like rice and noodles (Health Promotion Board Singapore, 2024b). The average per capita bread consumption in Singapore is approximately 13.3 kg per person annually (Ng, 2019). The revenue in the Bread & Bakery Products segment in Singapore is projected to reach approximately USD 614.8 million in 2024, with the market expected to grow 5.09% annually (Statista, nd). This consistent and substantial market size underscores the persistent economic and dietary importance of bread. Its high consumption rate positions packaged bread as a major vehicle for delivering both energy and targeted nutrients to the population (Kaim & Goluch, 2023).

The dietary implications of sodium and calcium contents in packaged bread remain relatively unknown. While bread can be fortified with calcium, its sodium content raises concerns about whether the health risks of sodium outweigh the nutritional benefits of calcium. This study identified specific forms of added sodium and calcium and evaluated their prevalence in packaged bread products in the Singaporean market. It also evaluated the influence of wholegrain and mineral additions on the calcium-to-sodium (Ca:Na) mass ratio. The study assessed whether current commercial bread formulations effectively delivered calcium without exceeding the recommended sodium thresholds.

## 2. MATERIALS AND METHODS

### 2.1 Study design and sampling

A cross-sectional study design was used to evaluate the nutritional composition of packaged bread in Singapore. A stratified random sampling approach was implemented in the five regions, Central, North, South, East, and West, to ensure a representative geographical sampling. Within each stratum, two supermarket outlets were randomly selected as the primary sampling sites. Only wheat-based breads packaged with mandatory nutritional labeling and available for retail during the three-month sampling window (July–September 2025) were included in the study. All products that met the inclusion criteria were procured from the selected sites for subsequent analysis.

### 2.2 Data collection and classification

Trained technicians systematically abstracted ingredient data, specifically regarding calcium, sodium, and wholegrain additives, from mandatory product labeling. Products were categorized as containing "added" constituents if the ingredient list specified at least one corresponding additive. This binary classification ensured a standardized assessment of fortification across the sampled inventories.

### 2.3 Variable calculation and statistical analysis

The percentages of the RDA (%RDA) for calcium and sodium were determined using established reference values (Health Promotion Board Singapore, 2022b). The Ca:Na mass ratio was calculated for each product by dividing the declared calcium content (mg) by the sodium content (mg) per serving size. Owing to the voluntary nature of calcium declaration under Singaporean food labeling standards (Health Promotion Board Singapore, 2024a), calcium data were unavailable for 55 products ( $n = 55$ ) in this study. Two distinct analytical frameworks were implemented to account for these missing values: 1. Undeclared calcium was treated as 0 mg/ serving to reflect a baseline scenario; and 2. A subset of products with explicit calcium labeling was analyzed to evaluate the fortification segment.

Scalar data were expressed as mean $\pm$ SD. One-sample *t*-tests were used to evaluate the deviations of sample means from established reference values. Comparisons between independent subgroups were performed using independent two-sample *t*-tests. All statistical assessments were two-tailed, with a significance threshold of  $p < 0.05$ .

## 3. RESULTS

### 3.1 Nutritional demographics

A total of 79 unique packaged bread products ( $n = 79$ ) met the inclusion criteria and were included in the final analyses. The nutritional profiles of the sampled products are presented in Table 1. On average, a single serving of the sampled bread contributed 12.1 $\pm$ 7.5% and 5.7 $\pm$ 9.7% to the Recommended Dietary Allowance (%RDA) for sodium and calcium, respectively (Health Promotion Board Singapore, 2022b).

<b>Table 1. Nutritional Composition of Packaged Bread Products (N=79) Sold in Singaporean Supermarkets</b>		
	<i>N</i>	<i>Mean±SD</i>
<b>Serving Size (g)</b>	79	54.9±24.4
<b>Energy (kcal/ serving)</b>	79	179.6±96.0
<b>Protein (g/ serving)</b>	79	4.6±2.8
<b>Fat (g/ serving)</b>	79	5.3±4.3
<b>Saturated Fat (g/ serving)</b>	78	2.8±2.6
<b>Tran Fat (g/ serving)</b>	75	0.1±0.6
<b>Carbohydrate (g/ serving)</b>	79	27.1±16.2
<b>Sugar (g/ serving)</b>	73	5.2±4.1
<b>Dietary Fibre (g/ serving)</b>	74	2.1±2.9
<b>Cholesterol (mg/ serving)</b>	69	2.6±11.7
<b>Sodium (mg/ serving)</b>	79	241.7±149.2
<b>Calcium (mg/ serving)</b>	79	45.5±77.8
<b>Calcium-to-Sodium Ratio</b>	79	0.2±0.3

3.2 Additive prevalence and co-occurrence

Sodium and calcium additives were identified in 94.9% and 38.0% of the evaluated bread products (n = 79), respectively. Regarding sodium, the majority of the samples (82.3%) contained a single additive, whereas 11.4% contained two, and 1.3% contained three. For calcium, 34.2% of products utilized a single additive, and 3.8% utilized two.

The concurrent presence of both sodium and calcium additives was observed in 36.7% of products. The most prevalent co-occurrence profile was the combination of one sodium and one calcium additive (24.1%), followed by two sodium additives and one calcium additive (8.9%). Rare combinations included one sodium with two calcium (2.5%) and three sodium with two calcium (1.3%); notably, no products exhibited a profile of two sodium and two calcium additives.

3.3 Ingredient characterization

Sodium chloride was the predominant sodium additive, being declared in 94.9% of the samples. Sodium bicarbonate (alternatively listed as sodium hydrogen carbonate) was the second most frequently used sodium additive (6.3%), followed by sodium aluminum phosphate (5.1%) and sodium caseinate (1.3%). Among the calcium sources, calcium carbonate was the primary additive (21.5%). Other identified sources included calcium sulfate (7.6%), calcium propionate (6.3%), calcium phosphate (5.1%), and calcium hydroxide (1.3%).

3.4 Assessment of calcium-to-sodium mass ratio and ingredient influence

The total analyzed cohort (n=79) exhibited a mean Ca:Na ratio of 0.2±0.3 (Table 1). A one-sample *t*-test confirmed that this value was significantly lower than the reference value of 1.0 (*p* < 0.0001). The distribution of ratios was heavily skewed toward

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lower values. 62.0% (n=49) of products had a ratio of <0.1, 19.0% (n=15) fell between 0.1–0.49, and 17.7% (n=14) ranged from 0.5 to 0.99. Only one product (1.3%) met the nutritional reference target of ≥1.0.

Analysis of the products with declared calcium content (n=33) revealed mean sodium and calcium concentrations of 199.8±89.1 and 109.0±87.2 mg/serving, respectively, resulting in a mean Ca:Na ratio of 0.5±0.3. These products contributed 10.0±4.5% of the RDA for sodium and 13.6±10.9% for calcium per single serving (Health Promotion Board Singapore, 2022b).<sup>11</sup> The calcium-declared subset exhibited significantly lower sodium content, higher calcium content, and higher Ca:Na ratios compared to products without declared calcium (Table 2). While calcium concentrations and Ca:Na ratios in this subset were significantly higher than those in the imputed dataset (two-sample *t*-test, *p* < 0.0001), the mean Ca:Na ratio remained significantly below the 1.0 reference value (one-sample *t*-test, *p* < 0.0001). The frequency distribution for this subset was: <0.1 (9.1%, n=3); 0.1–0.49 (45.5%, n=15); 0.5–0.99 (42.4%, n=14); and ≥ 1.0 (3.0%, n=1).

Although calcium and sodium additions increased the respective elemental concentrations in the packaged bread products, only calcium fortification significantly elevated the calcium contents of the final products (Table 2). Notably, calcium enrichment resulted in a significantly higher Ca:Na mass ratio than that in the control samples (Table 2). Conversely, the addition of sodium had no significant effect on the Ca:Na ratio (Table 2). The inclusion of whole-grain components resulted in no statistically significant alterations in the concentrations of calcium or sodium, nor did it impact the Ca:Na mass ratio (*p* > 0.05; Table 2).

**Table 2. Sodium and calcium content and calcium-to-sodium mass ratios of packaged bread products (n=79), stratified by additive declaration and whole grain composition.**

Packaged bread products	n	Sodium (mg/ serving)		Calcium (mg/ serving)		Calcium-to-sodium mass ratio	
		mean±SD	<i>p</i> <sup>1</sup>	mean±SD	<i>p</i> <sup>1</sup>	mean±SD	<i>p</i> <sup>1</sup>
<b>Calcium additives</b>							
<i>Without</i>	49	257.8±177.2	0.153	6.3±35.8	0.000	0.0±0.1	0.000
<i>With</i>	30	215.4±81.9		109.7±85.3		0.5±0.3	
<b>Sodium additives</b>							
<i>Without</i>	4	160.8±103.5	0.199	12.8±24.3	0.056	0.1±0.2	0.259
<i>With</i>	75	246.0±150.5		47.3±79.3		0.2±0.3	
<b>Wholegrains</b>							
<i>Without</i>	61	233.2±148.5	0.367	41.0±80.9	0.288	0.2±0.3	0.146
<i>With</i>	18	270.4±152.1		61.1±65.8		0.3±0.3	
<b>Declared calcium label</b>							
<i>Without</i>	46	271.7±175.2	0.020	0.0±0.0	0.000	0.0±0.0	0.000
<i>With</i>	33	199.8±89.1		109.0±87.2		0.5±0.2	
<sup>1</sup> <i>p</i> value without vs. with calcium, sodium, or wholegrain additives or declaring calcium contents using a two-sample independent <i>t</i> -test.							

#### 4. DISCUSSION

Bread is classified as a reliable vehicle for mass fortification because of its high daily consumption rates as a staple food and its unique physicochemical properties (Health Promotion Board Singapore, 2024b; Ng, 2019; Statista, nd). Its staple role in the diet allows for "passive" nutrient intake and avoids the behavioral barriers associated with voluntary supplement use (Kaim & Goluch, 2023). The structural matrix of bread is highly conducive to fortification. The robust starch-protein complex can accommodate significant mineral loads without compromising sensory attributes. The gluten network also effectively suspends insoluble additives, such as calcium carbonate, preventing the sedimentation issues typical of liquid delivery systems (Mesta-Corral *et al.*, 2024).<sup>12</sup> During fermentation, the activation of endogenous phytase enzymes degrades phytates and enhances mineral bioavailability (Gupta *et al.*, 2013). The production of organic acids, such as lactic and acetic acid, during fermentation also lowers the pH, acidifies, and solubilizes calcium salts, pre-conditioning them for more efficient absorption within the gastrointestinal tract (Wang & Wang, 2024).

The observation that a single serving of packaged bread contributes approximately 12.1% of the WHO's daily maximum sodium intake limit of 2,000 mg/day requires critical appraisal (World Health Organization, 2025; Health Promotion Board Singapore, 2022a). Although this percentage appears nominal in isolation, its nutritional significance is amplified by the ubiquity of bread as a dietary staple and the principle of cumulative exposure. The total sodium load from a single composite meal can constitute a substantial fraction of the daily threshold, because bread is frequently consumed with sodium-laden accompaniments (Sebastian *et al.*, 2015). Although sodium is essential for physiological events, including nerve transmission and osmotic regulation (Bernal *et al.*, 2023), chronic overconsumption of sodium is a primary etiological factor in hypertension, as it promotes fluid retention and increases hemodynamic strain on arterial walls (Surma *et al.*, 2025). High sodium exposure is implicated in independent pathological mechanisms, including increased arterial stiffness, endothelial dysfunction, and progressive target organ damage affecting the renal and cardiovascular systems (Surma *et al.*, 2025). The current average sodium intake among Singapore residents is approximately 4,000 mg/day, which doubles the recommended daily limit (Health Promotion Board Singapore, 2022a). Packaged bread, as a dietary staple, may be a critical driver of sodium excess. Sodium chloride, the most common sodium additive in packaged bread, maintains the rheological stability and fermentative balance of bread dough (Musienko *et al.*, 2025). Extracellular Na<sup>+</sup> ions draw water from yeast cells via osmosis, effectively regulating yeast activity, preventing "runaway" fermentation, which would otherwise lead to the deterioration of dough handling properties (Shirvanyan & Trchounian, 2024). Sodium chloride strengthens the gluten matrix by reducing the electrostatic repulsion between gliadin and glutenin chains, and allowing for closer protein aggregation (Yang *et al.*, 2025). The increased structural integrity effectively entraps carbon dioxide gas during fermentation, which ultimately refines the crumb architecture and optimizes the final loaf volume (Yang *et al.*, 2025).

The finding that packaged bread contributes 5.7 to 13.6% of the daily calcium intake highlights its role as a critical, "invisible" nutritional source. Bread can serve as a primary vehicle for calcium delivery, effectively bridging the gap between deficient and adequate intake without necessitating behavioral shifts, especially for individuals who are lactose intolerant or who consume little dairy. Flour fortification was shown to reduce the prevalence of calcium inadequacy by approximately 16 percentage points, shifting deficiency rates from 54% to 38% (Palacios *et al.*, 2020). The absorption rate of calcium in white and whole wheat bread was reported to be approximately 99% relative to calcium sulfate, a level comparable to the bioavailability of calcium in milk (~113%), suggesting that the calcium in bread exhibits high bioavailability (Ranhotra *et al.*, 1981). The supposedly insignificant 13.6% contribution may exert profound cumulative effects on long-term health outcomes, particularly regarding bone mineral density (BMD). Calcium-fortified foods increase BMD at the femoral neck and hip, and provide a critical buffer against age-related bone loss and fracture risk in older adults (Cormick *et al.*, 2021). Adequate calcium intake is also critical for children and adolescents for the accretion of peak bone mass, a developmental milestone that cannot be fully corrected later in life (Theobald, 2005). Reduced risk of preeclampsia and gestational hypertensive disorders has been strongly linked to adequate calcium intake, making calcium-fortified bread a life-saving intervention in populations with poor diet quality (Cormick *et al.*, 2024). These findings validate the success of "silent" public health interventions using packaged bread, ensuring that poor diet quality groups who often rely on starchy staples can access essential minerals despite the high cost of dairy or supplements. While significant, this 13.6% contribution remains a fraction of the daily 1,000 mg daily requirement. In view of this limitation, public health communication must position bread as a complementary source rather than a total replacement for calcium-dense whole foods, such as dairy, fortified plant milks, or leafy greens.

The dominance of calcium carbonate (21.5%) alongside functional additives such as calcium propionate (6.3%) illustrates a dual-purpose strategy of integrating nutritional fortification with technical performance, such as preservation and dough conditioning in industrial baking. Calcium carbonate, due to its high elemental density of approximately 40% calcium by weight, remains the global industry standard for mass-market fortification. It enables manufacturers to reach nutritional targets with minimal powder volume, thereby preserving the bread's sensory profile (National Institutes of Health, 2025). Calcium carbonate serves as a chemical buffer, stabilizing dough pH to protect the gluten network from excessive acidity, while its fine particle size ensures a smooth crumb texture free from the grittiness associated with coarser salts (Alsuhaibani, 2018; Romanchik-Cerpovicz & McKemie, 2007). The prevalence of calcium propionate (6.3%) represents a form of "incidental fortification." Primarily utilized as an antimicrobial agent, the calcium within this preservative is highly soluble and bioavailable (Kagliwal *et al.*, 2021). The eventual

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product receives a nutritional attribute as a secondary effect of shelf-life extension. Calcium sulfate (7.6%) is similarly utilized for its “calcium bridging” properties in which  $\text{Ca}^{2+}$  ions interact with anionic sites on glutenin and gliadin chains and create cross-links that reinforce the gluten network (Sehn *et al.*, 2015). The resulting strengthened structure ensures gas retention and uniform crumb architecture vital for high-volume or high-fiber loaves. Calcium phosphate (5.1%) provides phosphorus for bone mineralization, catalyzes fermentation, and influences surface pH to promote crust browning via the Maillard reaction (Gélinas, 2022; El Hosry *et al.*, 2025). The dual roles of calcium additives present a significant synergy where the functional necessity in modern food processing technology inadvertently reinforces micronutrient security.

The insoluble calcium carbonate reacts with gastric hydrochloric acid to release free calcium ions, rendering it highly bioavailable (Shkemi & Huppertz, 2021).<sup>33</sup> Its bioavailability, however, may be diminished in individuals with achlorhydria, a condition prevalent in elderly populations (Shkemi & Huppertz, 2021). Calcium propionate, as an organic salt, maintains high water solubility regardless of gastric acid levels, while the absorption rates of calcium sulfate are comparable to those of milk (Zhang *et al.*, 2020). The calcium additives utilized in the studied packaged bread are capable of exhibiting moderate to high bioavailability, especially with absorption via passive diffusion in the small intestine under high localized calcium concentrations (Burns-Whitmore *et al.*, 2024). Calcium bioavailability is also influenced by the presence of phytates. Phytate entraps free  $\text{Ca}^{2+}$  ions, forming insoluble calcium-phytate complexes that cannot be absorbed at the physiological pH of the small intestine (Killilea *et al.*, 2024). The phytate interference is negligible in white bread, as the milling process removes the bran and its associated phytate content (Killilea *et al.*, 2024). The fermentation stage of bread-making also activates endogenous phytase that catalyzes the degradation of phytates, thereby increasing calcium bioavailability (Gupta *et al.*, 2013).

The Ca:Na mass ratio serves as a potential index of nutritional quality, specifically regarding BMD maintenance and hypertension management (Gupta *et al.*, 2023; Hamer *et al.*, 2024). While no single global regulatory standard dictates this ratio, a mass ratio approaching or exceeding 1:1 is considered physiologically favorable (Gupta *et al.*, 2023; Hamer *et al.*, 2024). A diet where calcium intake equals or exceeds sodium intake is correlated with a decreased risk of both osteoporosis and hypertension (Hamer *et al.*, 2024; Caffarelli *et al.*, 2025). The observed statistically significant negative deviation ( $p < 0.005$ ) from the 1.0 target in commercial packaged bread is concerning, given its status as a dietary staple. A mean ratio of 0.2 indicates that for every unit of calcium, the consumer ingests five times the amount of sodium on average, creating a profound nutritional imbalance. The presence of phytates in bread further diminished calcium availability, suggesting that the physiological Ca:Na ratio may effectively be even lower than chemical analysis indicates (Burns-Whitmore *et al.*, 2024). The data revealed that 62% of products possessed a ratio below 0.1, a deficit possibly driven primarily by the high concentration of sodium chloride required for bread rheology. This nutritional disparity reflects the functional constraints of modern baking processes. Wheat flour is naturally deficient in calcium; without explicit fortification (e.g., calcium carbonate) or the use of functional additives (e.g., calcium propionate), the calcium numerator remains negligible (Mystkowska *et al.*, 2024). Achieving a 1:1 ratio requires either a drastic reduction in sodium additives, which compromises the dough texture and gas retention, or aggressive calcium fortification. Excessive calcium loading affects dough pH, potentially inhibits yeast kinetics, and imparts undesirable sensory attributes, such as a chalky or bitter flavor profile (Delompré *et al.*, 2019; Vargas & Simsek, 2021). The most critical health implication of these data involves the synergistic effect of sodium on renal calcium reabsorption. Within the proximal tubule of the nephron, sodium and calcium share a common transport mechanism; consequently, High dietary sodium intake creates an osmotic drag and inhibits the reabsorption of calcium within the proximal tubule of the nephron (Hakimi *et al.*, 2023). Approximately 20–40 mg of calcium is simultaneously lost in the urine for every 2,300 mg of sodium excreted by the kidneys (Hakimi *et al.*, 2023). The low Ca:Na ratios suggest that frequent consumption of these products fosters a “calciuretic” environment. The body resorbs bone tissue to compensate for the urinary calcium losses in order to maintain calcium homeostasis. Over time, a dietary pattern dominated by foods with a Ca:Na ratio below 1.0 contributes significantly to the progression of osteopenia and osteoporosis (Caffarelli *et al.*, 2025; John *et al.*, 2024). While sodium is a recognized risk factor for hypertension, calcium serves as a critical vasodilator and regulator of smooth muscle contraction (Gupta *et al.*, 2023; Hamer *et al.*, 2024). A ratio below 1.0 indicates a profound deficiency of the anti-hypertensive calcium alongside an excess of hypertensive sodium, effectively compounding the overall hypertensive risk for the consumer.

Subset analysis of 33 packaged breads with declared calcium contents revealed a critical nuance that even products that presumably marketed themselves based on nutritional value by declaring calcium content fail to meet the physiological target Ca:Na ratio of 1.0. While the significant increase in the mean ratio from 0.2 to 0.5 suggests intentional fortification or the use of functional additives, the fact that 97% of this high-performing group still misses the target highlights a systemic disconnect between food labeling regulations and metabolic physiology. Many products in this subset likely achieve an intermediate ratio (0.1–0.49) through the use of Ca additives. While these additives lift the product out of the lowest nutritional tier ( $< 0.1$ ), they cannot propel it to the 1.0 target independently. The data imply a strategy of “technological inertia” where manufacturers increase the calcium numerator through simple “dump and mix” operations rather than undertaking the complex re-engineering of the gluten network required to decrease the sodium denominator. This leads to a nutritional paradox in health claims. Under current regulations, a solid food qualifies as a “Source of Calcium” if it contains 15% of the RDA per 100g (120 mg) and “High in Calcium” if it meets 30% (240 mg) (Health Promotion Board Singapore, 2024a). A packaged bread product can legally satisfy these mass thresholds while

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maintaining a suboptimal Ca:Na ratio. Even though a mean Ca:Na ratio of 0.5 is an improvement over 0.2, the sodium load remains high enough to trigger hypercalciuria (Imash *et al.*, 2025). While these bread products may be less "osteopathogenic" than those without calcium declarations, they cannot yet be classified as "osteoprotective" (John *et al.*, 2024). The finding that "whole grain" status did not significantly influence mineral content challenges common consumer perceptions. Although wheat bran is naturally richer in minerals than the refined endosperm, its bioavailability is traditionally limited by its phytate content. Taken together, the data demonstrate that active calcium declaration alone is insufficient to address public health concerns; the core issue remains the metabolic antagonism created by excessive sodium, which necessitates a more holistic approach to food formulation.

The strategic integration of calcium fortification and sodium reduction in packaged bread highlights the sophisticated intersection of public health nutrition and industrial food science. Emerging "bio-organic" strategies, such as the use of micronized chicken eggshell, further enhance this matrix by introducing transport proteins like ovotransferrin to potentially improve intestinal calcium absorption (Kobus-Cisowska *et al.*, 2020). The nutritional efficacy of these fortified staples is often compromised by the high sodium chloride content required for dough rheology. Addressing this imbalance necessitates a "stealth health" framework that employs potassium chloride to substitute sodium chloride in maintaining electrostatic shielding of the gluten network, alongside enzymatic reinforcement with glucose oxidase to preserve dough tenacity (Codinã *et al.*, 2021; Konieczny *et al.*, 2020). Hydrocolloids like xanthan gum can be added to ensure moisture retention and gas cell stability. Fermentation introduces organic acids and umami-rich peptides that compensate for the sensory loss associated with lower salt concentrations (Islam & Islam, 2024; Zhang *et al.*, 2025). By decoupling nutritional enhancement from consumer behavioral change through these technological interventions, bread serves as a scientifically sound vehicle for improving population-wide micronutrient security without sacrificing the mechanical properties or palatability essential for industrial scalability.

A primary limitation of the current study is the absence of direct *in vivo* or *in vitro* assessment of the bioavailability of calcium and sodium within the packaged bread matrix. Quantifying elemental calcium and sodium concentrations and calculating the Ca:Na mass ratio offer a structural nutritional profile, but these metrics do not account for the fractions of the nutrients that are physiologically not bioavailable. The bioavailability of these minerals from fortified bread may be significantly influenced by the presence of phytates that sequester cations, potentially overestimating the nutritional bioavailability and efficacy of the product based on label declarations alone. Future research incorporating bioavailability assays is required to accurately map the metabolic effects of these commercial bread products. The sample size of 79 unique packaged bread products was determined by a stratified random sampling protocol designed to capture a representative cross-section of the Singaporean retail market rather than an *a priori* statistical power calculation. Sampling was distributed across Singapore's Central, North, South, East, and West regions, with two supermarket outlets randomly selected within each stratum, to ensure geographical representativeness. The final sample size was defined by the exhaustive procurement of all packaged bread products meeting specific inclusion criteria—wheat-based packaged breads with mandatory nutritional labeling—available between July and September 2025. The sample size reflects the actual commercial inventory accessible to consumers, prioritizing ecological validity over arbitrary statistical targets.

## **5. CONCLUSION**

Bread is a scientifically practical vehicle for fortification because it decouples nutritional interventions from behavioral changes. However, its effectiveness is currently limited by the metabolic antagonism between calcium and sodium. Future innovations in food science must focus on reducing sodium levels through enzymatic modification and mineral alternatives while optimizing the bioavailability of calcium. A holistic approach that considers the total renal load and Ca:Na mass ratio, rather than simple mass thresholds, is essential for transforming bread from a dietary staple into a truly osteoprotective food.

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## **8. CONFLICT OF INTEREST**

The authors do not have any conflicts of interest.

## **9. DATA AVAILABILITY STATEMENT**

The data that support the findings of this study are available from the corresponding author, WML, on special request.

## **10. ETHICS STATEMENT**

The study does not involve human participants and animal subjects, or any material that requires ethical approval.

## **11. INFORMED CONSENT STATEMENT**

The study does not involve human participants, and therefore, informed consent was not required.

## **12. CLINICAL TRIAL REGISTRATION**

This research does not involve any clinical trials.

## **13. AUTHORS' CONTRIBUTION**

Wai Mun Loke: Conceptualization, Methodology, Data Curation, Formal Analysis, Writing – Original Draft, Writing – Original Draft, Reviewing and Editing, Supervision.

Jamie Shi Mei Tan: Data Curation, Formal Analysis, Writing – Reviewing and Editing.

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