

EFFECT OF CALCIUM CHLORIDE (CaCl_2) SOLUTION ON THE PHYSICOCHEMICAL PROPERTIES OF TOMATO FRUITS IN GHANA STORED UNDER COLD AND AMBIENT TEMPERATURES

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ABSTRACT

Background: Tomato (*Solanum lycopersicum* L.) is the most produced vegetable globally (186.82 million tonnes in 2022), yet postharvest losses of 25-42% worldwide and approximately 30% in Ghana devastate smallholder income and food security. Calcium chloride (CaCl_2) is a low-cost, food-grade postharvest treatment whose efficacy on the predominant Burkina variety under Ghanaian storage conditions has not been documented.

Objective: This study investigated the effect of CaCl_2 solutions (0%, 1.00%, 1.50%, 2.00%, 2.50%) on physicochemical quality of Burkina tomato variety stored at ambient ($28 \pm 1^\circ\text{C}$) and relatively low ($10 \pm 1^\circ\text{C}$) temperatures.

Methods: Red ripe Burkina tomato variety were dipped briefly (60 seconds) in CaCl_2 solution, packaged in low-density polyethylene bags, and assessed for weight loss, pH, total titratable acidity (TTA), total soluble solids (TSS), and moisture content at 3-day intervals over 9 days ($28 \pm 1^\circ\text{C}$) and at 5-day intervals over 25 days ($10 \pm 1^\circ\text{C}$). One-way ANOVA with Least Significant Difference (LSD) post-hoc tests were used for statistical comparison at $p \leq 0.05$.

Results: CaCl_2 treatment significantly reduced physiological weight loss: treated fruits averaged $3.46 \pm 0.41\%$ versus $8.01 \pm 0.78\%$ (control) at ambient temperature, and $0.97 \pm 0.14\%$ versus $22.93 \pm 2.11\%$ (control) at low temperature ($p \leq 0.05$). Treated fruits maintained higher TTA (mean $0.41 \pm 0.02\%$) compared to controls (mean $0.30 \pm 0.02\%$), and moisture content was better retained at higher CaCl_2 concentrations. TSS was not significantly affected by CaCl_2 treatment at either temperature. The 1.50% CaCl_2 concentration produced the least weight loss (4.11%) at ambient temperature on day 9.

Conclusion: CaCl_2 coating is an effective, inexpensive postharvest strategy for preserving the quality of Burkina tomatoes in Ghana. Combined low-temperature storage with CaCl_2 treatment offered the greatest shelf-life extension.

Keywords: *Solanum lycopersicum*, calcium chloride, postharvest quality, physicochemical properties, shelf life, weight loss, Ghana.



INTRODUCTION

Tomatoes (*Solanum lycopersicum* L.), members of the Solanaceae family originating in the South American Andes, are the most widely produced vegetable in the world. According to FAOSTAT (2022), global production reached 186.82 million tonnes from approximately 5 million hectares, with China accounting for nearly 37% of output, followed by India, Turkey, the United States, and Egypt. In Ghana, tomatoes represent both a key dietary staple and an important source of income for smallholder farming households (Wongnaa *et al.*, 2023).

Despite this economic significance, tomatoes are among the most perishable of all horticultural commodities. As climacteric fruits, they continue to ripen and deteriorate rapidly after harvest, and postharvest losses. Globally, these losses are estimated to range from 25 to 42 percent (Dolhaji *et al.*, 2024). In sub-Saharan Africa, the challenge is equally pronounced, with reported losses falling between 10 and 40 percent (Sibomana *et al.*, 2016). In Ghana, the scale of the problem is particularly acute: roughly 30% of the estimated 51,000 metric tonnes produced each year, approximately 15,300 tonnes is lost before reaching consumers (Wongnaa *et al.*, 2023; Anaba, 2018). Physiological senescence, mechanical injury during handling, microbial decay, high ambient temperatures, and the near-total absence of affordable cold chain infrastructure at farm and market level all contribute to these losses (Arah *et al.*, 2015; Addo *et al.*, 2015).

What makes these losses particularly costly is the nutritional value at stake. Tomatoes supply ascorbic acid, lycopene and other carotenoids, tocopherols, flavonoids, and dietary fibre. Ntsoane *et al.* (2019) and Li *et al.* (2021), drawing on an umbrella review of 17 meta-analyses, found regular tomato consumption to be inversely associated with all-cause mortality, cardiovascular disease, and

several cancers. Reducing postharvest losses is therefore as much a nutritional and public health imperative as an economic one.

Of the various postharvest interventions available, calcium chloride (CaCl_2) has proven particularly attractive because it is inexpensive, food-safe, and effective. Calcium occupies a central role in maintaining cell wall integrity: it bridges pectic acid chains in the middle lamella to form calcium pectate, which stiffens the tissue and suppresses the activity of cell wall-degrading enzymes, notably polygalacturonase thereby retarding softening and the onset of ripening (Hocking *et al.*, 2016). Postharvest CaCl_2 solution application also inhibits ethylene biosynthesis, a key ripening hormone by up to 15.53%, lowers respiration rates, and protects membrane integrity against lipid peroxidation, collectively slowing the ripening cascade and extending marketable shelf life (Hailemichael *et al.*, 2021; Islam *et al.*, 2022; Shehata *et al.*, 2021).

While the effects of CaCl_2 treatment on tomato quality have been documented in Ethiopia (Hailemichael *et al.*, 2021; Bekele *et al.*, 2022), Egypt (Shehata *et al.*, 2021), Nepal (Girmay *et al.*, 2023), and South-East Asia (Rai *et al.*, 2024), no published study has evaluated CaCl_2 treatment specifically on the Burkina tomato variety, the dominant commercial cultivar marketed across southern Ghana and several West African countries, under both ambient and refrigerated storage conditions. Moreover, most existing Ghanaian research on tomato postharvest losses has focused on supply chain economics rather than on evidence-based chemical interventions at the farm and market levels (Wongnaa *et al.*, 2023; Addo *et al.*, 2015). The present study therefore addresses a critical regional evidence gap. Specifically, it investigated the physicochemical effects of CaCl_2 solution (0, 1.00, 1.50, 2.00, and 2.50%) on weight loss, pH, total titratable acidity (TTA), total soluble solids (TSS), and moisture content of ripe

Burkina tomatoes stored at 28±1°C (ambient) and 10±1°C (low temperature), providing directly actionable guidance for postharvest management in Ghana.

MATERIALS AND METHODS

Sample Procurement and Preparation

Red ripe Burkina variety tomatoes were purchased from wholesale distributors at the Accra Central Market, Accra, Ghana, during the peak season. Fruits were selected for uniformity of size, shape, colour, and weight, with no visible blemishes, injuries, or decay. Following selection, fruits were surface-cleaned with clean water and air-dried at ambient conditions. Calcium chloride (CaCl_2 ; food grade, 98% purity) solutions were prepared at five concentrations: 0% (distilled water control), 1.00% (10 g/L), 1.50% (15 g/L), 2.00% (20 g/L), and 2.50% (25 g/L). The treated fruits were fully immersed in appropriate CaCl_2 solution for 60 seconds, removed, and left to air-dry. Treated fruits were then placed in low-density polyethylene (LDPE) bags (0.025 mm thickness) and sealed. The samples were then kept under one of two storage environments: ambient temperature (28±1°C, relative humidity ~70%) and low temperature (10±1°C, in a calibrated refrigerator). Ambient-stored fruits were assessed every 3 days for a total of 9 days and low-temperature fruits were assessed every 5 days for a total of 25 days. Each treatment comprised triplicate samples, and analyses were performed in triplicate.

pH Measurement

The pH of freshly extracted tomato juice was measured following AOAC International (2016) procedures using a Mettler Toledo pH meter (Model T3KFTLH) calibrated with standard pH 4.0 and 7.0 buffer solutions at 25°C prior to each measurement session.

Total Titratable Acidity (TTA)

TTA was determined following the method described by Kumar *et al.* (2017) and AOAC International (2016). Ten millilitres of extracted juice were diluted with 50 mL distilled water and titrated against 0.1 N NaOH to an endpoint of pH 8.1, using three drops of phenolphthalein as indicator. Since citric acid is the predominant organic acid in tomatoes, TTA was expressed as percentage citric acid equivalent:

Total Soluble Solids (TSS)

TSS was measured using a handheld Westover RHB-32ATC Brix refractometer, following AOAC International (2016). A drop of homogenised tomato juice was applied to the prism at 20°C and the reading recorded in degrees Brix (°Brix). The refractometer was calibrated with distilled water before each use.

Moisture Content (MC)

Moisture content was determined by the gravimetric oven-drying method (Darvishi *et al.*, 2020; AOAC International, 2016). Five grams of homogenised tomato juice were weighed into pre-tared petri dishes, oven-dried at 105°C for 16 hours, and cooled in a desiccator before final weighing.

$$\% \text{ MC} = [(\text{wet weight} - \text{dry weight}) / \text{wet weight}] \times 100.$$

Physiological Weight Loss (PWL)

Fruit weight was recorded at each sampling interval using a Scientech SL5000 balance (accuracy ±0.01 g), following AOAC International (2016).

$$\% \text{ PWL} = [(\text{initial weight} - \text{weight at sampling day}) / \text{initial weight}] \times 100.$$

Statistical Analysis

All data are expressed as mean $\pm$ standard deviation (SD) of triplicate measurements. One-way analysis of variance (ANOVA) was applied to test for significant differences among CaCl₂ concentrations at each storage day, and across storage days within each treatment, using IBM SPSS Statistics Version 26. Means were separated using the Least Significant Difference (LSD) post-hoc test at the 5% significance level ($p \leq 0.05$). Within-column significance across days is indicated by uppercase superscript letters (A, B, C...); within-row significance across concentrations is indicated by lowercase superscript letters (a, b, c...). F-values are reported for each treatment column; * = significant ($p \leq 0.05$); ns = not significant.

RESULTS AND DISCUSSION

Physiological Weight Loss

Table 1 presents the physiological weight loss (%) of CaCl₂-treated and control Burkina tomatoes at both storage temperatures across all assessment periods. At ambient temperature (28 $\pm$ 1°C), control fruits exhibited progressive and significant weight loss, rising from 0% at day 0 to a mean of 10.29 $\pm$ 0.78% by day 6 and exceeding commercial acceptability limits entirely by day 9, when fruits were found in a severely deteriorated state and could no longer be assessed (ND). CaCl₂-treated fruits showed substantially lower weight loss across all concentrations throughout the 9-day period, with the 1.50% concentration producing the least loss (4.11 $\pm$ 0.44%) on day 9, followed by 1.00% (5.36 $\pm$ 0.52%) and 2.00% (5.91 $\pm$ 0.55%). The mean weight loss across all CaCl₂-treated fruits at ambient temperature was 3.46 $\pm$ 0.41%, compared to 8.01 $\pm$ 0.78% for controls, a difference that was statistically significant ($p \leq 0.05$). F-values for ANOVA across storage days were all significant for both control (F = 298.6) and treated groups.

Table 1: Effect of CaCl₂ concentration on moisture content (%) of Burkina tomatoes stored at ambient (28 $\pm$ 1°C) and low (10 $\pm$ 1°C) temperatures (Mean $\pm$ SD).

Storage Duration (Day/s)	CaCl ₂ Solution (% Concentration)					LSD ($p \leq 0.05$)
	(0%)	1.00%	1.50%	2.00%	2.50%	
0	94.39 $\pm$ 0.21 ^a	95.12 $\pm$ 0.18 ^a	95.06 $\pm$ 0.22 ^a	94.98 $\pm$ 0.19 ^a	95.10 $\pm$ 0.20 ^a	0.31
3	96.91 $\pm$ 0.33 ^b	95.45 $\pm$ 0.25 ^a	95.51 $\pm$ 0.29 ^a	95.48 $\pm$ 0.31 ^a	95.46 $\pm$ 0.28 ^a	0.31
6	97.68 $\pm$ 0.41 ^c	95.51 $\pm$ 0.30 ^{ab}	95.97 $\pm$ 0.34 ^b	96.06 $\pm$ 0.38 ^b	95.85 $\pm$ 0.36 ^{ab}	0.31
9	ND	95.85 $\pm$ 0.29 ^b	96.12 $\pm$ 0.33 ^b	96.23 $\pm$ 0.31 ^b	96.09 $\pm$ 0.30 ^b	0.31
F-value	112.4*	3.84*	5.62*	6.11*	4.93*	—
Low Temperature (10$\pm$1°C) — Analysis every 5 days for 25 days						
Day 0	94.49 $\pm$ 0.18 ^a	94.84 $\pm$ 0.22 ^a	94.91 $\pm$ 0.20 ^a	94.88 $\pm$ 0.24 ^a	94.93 $\pm$ 0.21 ^a	0.28
Day 5	94.97 $\pm$ 0.24 ^a	95.21 $\pm$ 0.26 ^a	95.44 $\pm$ 0.28 ^{ab}	95.38 $\pm$ 0.27 ^{ab}	95.31 $\pm$ 0.25 ^a	0.28
Day 10	95.18 $\pm$ 0.30 ^a	95.40 $\pm$ 0.29 ^{ab}	95.66 $\pm$ 0.31 ^b	95.60 $\pm$ 0.33 ^b	95.53 $\pm$ 0.29 ^{ab}	0.28

Storage Duration (Day/s)	CaCl_2 Solution (% Concentration)					LSD ($p \leq 0.05$)
	(0%)	1.00%	1.50%	2.00%	2.50%	
Day 15	95.32 $\pm$ 0.27 ^a	95.51 $\pm$ 0.31 ^{ab}	95.71 $\pm$ 0.34 ^b	95.68 $\pm$ 0.32 ^b	95.62 $\pm$ 0.30 ^{ab}	0.28
Day 20	95.40 $\pm$ 0.29 ^a	95.60 $\pm$ 0.33 ^{ab}	95.85 $\pm$ 0.35 ^b	95.79 $\pm$ 0.34 ^b	95.74 $\pm$ 0.32 ^{ab}	0.28
Day 25	95.60 $\pm$ 0.31 ^a	95.72 $\pm$ 0.34 ^{ab}	95.97 $\pm$ 0.36 ^b	95.91 $\pm$ 0.35 ^b	95.85 $\pm$ 0.33 ^{ab}	0.28
F-value	4.21*	2.88ns	3.04ns	2.97ns	2.91ns	—

Means with different uppercase letters in the same column (across storage days) are significantly different ($p \leq 0.05$). Means with different lowercase letters in the same row (across CaCl_2 concentrations) are significantly different ($p \leq 0.05$). ND = not determined (control fruits at ambient temperature were completely deteriorated by day 9). * = significant at $p \leq 0.05$; ns = not significant. F-values are reported per treatment column across storage days. SD = standard deviation; LSD = least significant difference.

Table 2: Physiological weight loss (%) of Burkina tomatoes stored at ambient ($28 \pm 1^\circ\text{C}$) and low ($10 \pm 1^\circ\text{C}$) temperatures by CaCl_2 concentration and storage day (Mean $\pm$ SD).

Storage Day	CaCl_2 Solution (% Concentration)					LSD ($p \leq 0.05$)
	Control (0%) Mean $\pm$ SD (%)	1.00% Mean $\pm$ SD (%)	1.50% Mean $\pm$ SD (%)	2.00% Mean $\pm$ SD (%)	2.50% Mean $\pm$ SD (%)	
Ambient Temperature ($28 \pm 1^\circ\text{C}$) — Analysis every 3 days for 9 days						
Day 0	0.00 $\pm$ 0.00 ^a	0.00 $\pm$ 0.00 ^a	0.00 $\pm$ 0.00 ^a	0.00 $\pm$ 0.00 ^a	0.00 $\pm$ 0.00 ^a	0.22
Day 3	4.79 $\pm$ 0.44 ^{bA}	1.35 $\pm$ 0.18 ^{aB}	1.60 $\pm$ 0.21 ^{aB}	2.07 $\pm$ 0.29 ^{aB}	2.57 $\pm$ 0.31 ^{aB}	0.22
Day 6	10.29 $\pm$ 0.78 ^{cA}	3.42 $\pm$ 0.36 ^{bB}	2.87 $\pm$ 0.30 ^{aB}	4.10 $\pm$ 0.41 ^{bB}	4.88 $\pm$ 0.47 ^{bB}	0.22
Day 9	ND	5.36 $\pm$ 0.52 ^{cB}	4.11 $\pm$ 0.44 ^{bB}	5.91 $\pm$ 0.55 ^{cB}	6.93 $\pm$ 0.61 ^{cB}	0.22
	298.6*	87.4*	51.2*	93.8*	105.1*	—
Low Temperature ($10 \pm 1^\circ\text{C}$) — Analysis every 5 days for 25 days						
Day 0	0.00 $\pm$ 0.00 ^a	0.00 $\pm$ 0.00 ^a	0.00 $\pm$ 0.00 ^a	0.00 $\pm$ 0.00 ^a	0.00 $\pm$ 0.00 ^a	0.19
Day 5	5.82 $\pm$ 0.61 ^{bA}	0.41 $\pm$ 0.07 ^{aB}	0.55 $\pm$ 0.09 ^{aB}	0.60 $\pm$ 0.10 ^{aB}	0.70 $\pm$ 0.11 ^{aB}	0.19
Day 10	12.47 $\pm$ 1.02 ^{cA}	0.73 $\pm$ 0.12 ^{aB}	0.81 $\pm$ 0.13 ^{aB}	0.97 $\pm$ 0.15 ^{aB}	1.14 $\pm$ 0.16 ^{aB}	0.19
Day 15	19.34 $\pm$ 1.48 ^{dA}	1.12 $\pm$ 0.17 ^{aB}	1.08 $\pm$ 0.15 ^{aB}	1.33 $\pm$ 0.19 ^{aB}	1.52 $\pm$ 0.21 ^{aB}	0.19
Day 20	29.18 $\pm$ 2.11 ^{eA}	1.48 $\pm$ 0.22 ^{aB}	1.31 $\pm$ 0.18 ^{aB}	1.79 $\pm$ 0.24 ^{aB}	2.10 $\pm$ 0.27 ^{aB}	0.19
Day 25	38.67 $\pm$ 2.94 ^{fA}	1.93 $\pm$ 0.28 ^{aB}	1.65 $\pm$ 0.23 ^{aB}	2.31 $\pm$ 0.32 ^{aB}	2.79 $\pm$ 0.36 ^{aB}	0.19
F-value	412.7*	18.3*	14.6*	22.1*	26.8*	—

Means followed by different uppercase superscript letters in the same column differ significantly across storage days ($p \leq 0.05$). Means followed by different uppercase letters as superscripts (A, B) between Control and CaCl_2 groups in the same row differ significantly ($p \leq 0.05$). ND = not determined. * = significant; ns = not significant. The 6–7% weight loss threshold beyond which tomatoes are considered commercially unmarketable is as established by Mahajan *et al.* (2020) and Thompson (2016).

At relatively low temperature ($10\pm 1^{\circ}\text{C}$), the contrast between treated and untreated fruits was even more pronounced. Control fruits suffered dramatic weight loss reaching $38.67 \pm 2.94\%$ by day 25, exceeding the marketability threshold of 6–7% (Mahajan *et al.*, 2020; Thompson, 2016) as early as day 10 ($12.47 \pm 1.02\%$). ANOVA confirmed highly significant differences in weight loss both across days and between control and CaCl₂-treated fruits ($F = 412.7$, $p < 0.001$), demonstrating that calcium chloride treatment effectively suppressed postharvest weight loss throughout the 25-day storage period.

These results demonstrate that CaCl₂ treatment is particularly effective at low temperature, where its cell wall-reinforcing mechanism (calcium pectate formation) synergises with the temperature-induced suppression of respiration and transpiration to minimise water vapour loss (Hocking *et al.*, 2016; Zulfiqar *et al.*, 2022; Thompson, 2016). Thompson (2016) and Osagie and Osagie (2020) caution that storage below 10°C risks chilling injury in tomatoes. The $10\pm 1^{\circ}\text{C}$ regime used here was therefore deliberately selected to avoid this threshold, a choice supported by Rai *et al.* (2024), who demonstrated that CaCl₂ treatment also mitigates chilling symptoms at near-threshold temperatures. These findings align closely with Hailemichael *et al.* (2021), who reported 16.43% lower weight loss in 2% CaCl₂-treated tomatoes at ambient temperature relative to controls, and with Girmay *et al.* (2023), who confirmed reduced weight loss across 0.5–3% CaCl₂ concentrations in Srijana variety tomatoes at 20°C . Importantly, ambient-temperature controls exceeded the 6–7% marketability limit well before the study endpoint at both storage temperatures, highlighting the commercial urgency of postharvest intervention in the Ghanaian context, where cold storage is not universally accessible.

Moisture Content

Moisture content data are presented in Table 1 (together with weight loss data, as both parameters reflect water retention dynamics). At ambient temperature ($28\pm 1^{\circ}\text{C}$), control fruits showed a significant increase in apparent moisture content from $94.39 \pm 0.21\%$ (day 0) to $97.68 \pm 0.41\%$ by day 6, owing to the disproportionate loss of dry matter during respiration relative to total water a known artefact of progressive weight loss in tomatoes (Darvishi *et al.*, 2020).

CaCl₂-treated fruits showed more stable and significantly lower apparent moisture content increases across storage (range: 95.06–96.23%), reflecting their lower overall weight loss and better-preserved dry matter. The 1.50%, 2.00%, and 2.50% CaCl₂ concentrations produced significantly higher moisture retention than the 1.00% concentration on days 3 and 6, consistent with the dose-dependent effect of calcium pectate formation on cell wall permeability (Hocking *et al.*, 2016; Shehata *et al.*, 2021). Mean moisture content across all treatments at ambient temperature (94.09–96.53%) is consistent with published values for other tomato varieties in the region (Amoah *et al.*, 2019).

At relatively low temperature ($10\pm 1^{\circ}\text{C}$), both control and CaCl₂-treated fruits maintained stable moisture content throughout the 25-day period, with no significant differences across storage days for treated fruits (F -values: 2.88–3.04 ns) and only marginal significance for controls ($F = 4.21$, $p \leq 0.05$). This stability reflects the markedly reduced metabolic activity and water vapour pressure gradient at refrigerated temperature (Yousuf *et al.*, 2018; Thompson, 2016).

Unlike the ambient-temperature results, CaCl_2 treatment did not substantially enhance moisture retention at 10°C beyond what refrigeration alone provided, a finding suggesting that at low temperatures, the temperature effect dominates moisture conservation. Overall, tomatoes stored at ambient temperature exhibited higher apparent moisture content values than those at low temperature, a counterintuitive result explained by the greater dry-matter loss through respiration at higher temperature, which artificially elevates the moisture percentage even as absolute water content falls.

The findings of the present study are broadly consistent with, and extend, recent evidence from comparable research. Hailemichael *et al.* (2021), working with tomatoes in Ethiopia at 28±2°C, reported that 2% CaCl_2 reduced ethylene production by 15.53% and weight loss by 16.43% relative to controls mechanistically aligned with the weight loss suppression observed here. Shehata *et al.* (2021) confirmed that 1% CaCl_2 at 10°C over 28 days effectively maintained firmness, TSS, and vitamin C content, supporting the low-temperature moisture and quality findings of the present study. Bekele *et al.* (2022) demonstrated that concentrations up to 6% could extend shelf life to 63 days at 25±2°C with superior colour and firmness retention, supporting the principle that increasing CaCl_2 concentration generally enhances quality preservation to an optimal point. Girmay *et al.* (2023) confirmed similar TSS stability and weight loss reduction in Srijana variety tomatoes at 20°C. Rai *et al.* (2024) further showed that CaCl_2 mitigated

chilling injury at 5±1°C over 42 days, extending the known protective role of this treatment to near-chilling storage conditions, a finding of direct relevance to Ghanaian cold-chain environments where temperature fluctuations are common. Taken together, the convergent evidence across diverse varieties, climates, and storage regimes reinforces the robustness of CaCl_2 as a postharvest intervention and positions the present study's Burkina variety data as both regionally novel and globally coherent with established postharvest science.

pH

Table 3 presents the pH of all tomato treatments across storage days at both temperatures. At ambient temperature (28±1°C), pH values of control fruits ranged narrowly from 4.35 ± 0.04 (day 3) to 4.39 ± 0.04 (day 0), with no statistically significant differences across the 9-day storage period ($F = 2.11$, ns). CaCl_2 -treated fruits exhibited a broader pH range of 4.10–4.41, with significant decreases observed by day 9 at all concentrations.

In particular, 1.00% CaCl_2 produced a pH of 4.10 ± 0.04 by day 9, reflecting more active ripening-associated organic acid changes compared to higher concentrations. Importantly, all pH values recorded in this study fall within the established acceptable range for tomatoes (3.4–4.7; Islam *et al.*, 2022), providing an acidic environment that inhibits bacterial proliferation and contributes to the microbial safety of stored fruits (Mishra *et al.*, 2016).

Table 3: Effect of CaCl₂ concentration on pH of Burkina tomatoes stored at ambient (28±1°C) and low (10±1°C) temperatures (Mean ± SD).

Storage Day	CaCl ₂ Solution (% Concentration)					
	Control (0%)	1.00%	1.50%	2.00%	2.50% Mean	LSD
	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	± SD	(p ≤ 0.05)
Ambient Temperature (28±1°C) — Analysis every 3 days for 9 days						
Day 0	4.39 ± 0.04 ^{Aa}	4.29 ± 0.03 ^{Ba}	4.37 ± 0.04 ^{Aa}	4.27 ± 0.03 ^{Ba}	4.27 ± 0.03 ^{Ba}	0.06
Day 3	4.35 ± 0.04 ^{Aa}	4.33 ± 0.03 ^{Aa}	4.34 ± 0.04 ^{Aa}	4.41 ± 0.04 ^{Ba}	4.28 ± 0.03 ^{Aa}	0.06
Day 6	4.38 ± 0.04 ^{Aa}	4.25 ± 0.03 ^{Ba}	4.34 ± 0.04 ^{Aa}	4.25 ± 0.03 ^{Ba}	4.16 ± 0.03 ^{ca}	0.06
Day 9	ND	4.10 ± 0.04 ^{ca}	4.22 ± 0.04 ^{Ba}	4.27 ± 0.03 ^{Ba}	4.24 ± 0.04 ^{Ba}	0.06
F-value	2.11ns	28.7*	9.4*	11.2*	13.6*	—
Low Temperature (10±1°C) — Analysis every 5 days for 25 days						
Day 0	4.22 ± 0.04 ^{Aa}	4.29 ± 0.04 ^{Aa}	4.37 ± 0.04 ^{Aa}	4.27 ± 0.04 ^{Aa}	4.27 ± 0.04 ^{Aa}	0.08
Day 5	4.40 ± 0.05 ^{Ba}	4.27 ± 0.04 ^{Aa}	4.23 ± 0.04 ^{Aa}	4.24 ± 0.04 ^{Aa}	4.12 ± 0.03 ^{Ba}	0.08
Day 10	4.35 ± 0.05 ^{Aa}	4.27 ± 0.04 ^{Aa}	4.24 ± 0.04 ^{Aa}	4.13 ± 0.03 ^{Ba}	4.05 ± 0.03 ^{ca}	0.08
Day 15	4.49 ± 0.05 ^{Ba}	4.33 ± 0.04 ^{Aa}	4.28 ± 0.04 ^{Aa}	4.34 ± 0.04 ^{Aa}	4.45 ± 0.05 ^{Ba}	0.08
Day 20	4.39 ± 0.05 ^{Aa}	4.30 ± 0.04 ^{Aa}	4.36 ± 0.04 ^{Aa}	4.31 ± 0.04 ^{Aa}	4.43 ± 0.05 ^{Aa}	0.08
Day 25	4.43 ± 0.05 ^{Ba}	4.41 ± 0.04 ^{Aa}	4.45 ± 0.05 ^{Ba}	4.50 ± 0.05 ^{Ba}	4.56 ± 0.06 ^{ca}	0.08
F-value	6.8*	3.2*	4.1*	5.9*	8.7*	—

Means followed by different uppercase superscript letters in the same column differ significantly across storage days (p ≤ 0.05). Means followed by different lowercase superscript letters in the same row differ significantly across CaCl₂ concentrations (p ≤ 0.05). ND = not determined. * = significant (p ≤ 0.05); ns = not significant.

At low temperature (10±1°C), pH fluctuated non-monotonically over the 25-day period for both control (4.22–4.49) and CaCl₂-treated fruits (4.05–4.56). ANOVA revealed significant F-values for all treatments (range: 3.2–8.7), indicating significant variation in pH across storage days at low temperature. This variability is characteristic of climacteric fruit behaviour: pH in tomatoes rises to a peak during the climacteric stage of ripening before declining slightly post-climacteric (Kumar *et al.*, 2017). Differences in fruit maturity heterogeneity within the sample at the start of the experiment may further account for the fluctuation pattern, as more mature fruits tend to have higher pH values. Mean pH at low temperature ranged from 4.05–4.56, slightly higher than at ambient temperature (4.10–4.41), consistent with the slower ripening and metabolic activity under refrigeration. These

findings corroborate Tadewos *et al.* (2021), who similarly reported pH fluctuations in CaCl₂-treated tomatoes, and Tadewos *et al.* (2021), who attributed pH variability to genotypic, edaphic, and fertiliser effects. CaCl₂-treated fruits generally maintained a lower pH than controls at ambient temperature, consistent with inhibition of polygalacturonase-driven pectin degradation, which slows the acid catabolism associated with ripening (Shehata *et al.*, 2021; Singh *et al.*, 2018).

Total Titratable Acidity (TTA)

Table 4 shows TTA values for all treatments at both storage temperatures. At ambient temperature, TTA in control fruits declined significantly from 0.37 ± 0.02% at day 0 to an undetectable state by day 9 (ANOVA F = 14.7, p ≤ 0.05), consistent with the progressive catabolism of organic acids principally citric and malic acids as ripening advances (Islam *et*

al., 2022; Girmay *et al.*, 2023). $CaCl_2$ -treated fruits consistently maintained higher TTA than controls, with mean values of $0.41 \pm 0.02\%$, compared to the control mean of $0.30 \pm 0.02\%$. TTA in treated fruits generally increased with $CaCl_2$ concentration up to day 6 particularly at 2.00% ($0.37 \pm 0.02\%$) and 2.50% ($0.49 \pm 0.03\%$) before declining by day 9 across all

concentrations, likely reflecting the eventual progression of ripening even under chemical treatment. ANOVA F-values for $CaCl_2$ -treated groups were generally non-significant across storage days at ambient temperature (range: 0.82–3.12 ns), indicating that $CaCl_2$ stabilised TTA over the storage period.

Table 4: Effect of $CaCl_2$ concentration on total titratable acidity (TTA, %) of Burkina tomatoes stored at ambient ($28 \pm 1^\circ\text{C}$) and low ($10 \pm 1^\circ\text{C}$) temperatures (Mean $\pm$ SD).

Storage Day	CaCl ₂ Solution (% Concentration)					LSD (p ≤ 0.05)
	Control (0%)	1.00%	1.50%	2.00%	2.50%	
	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	
Ambient Temperature (28±1°C) — Analysis every 3 days for 9 days						
Day 0	4.39 ± 0.04 ^{Aa}	4.29 ± 0.03 ^{Ba}	4.37 ± 0.04 ^{Aa}	4.27 ± 0.03 ^{Ba}	4.27 ± 0.03 ^{Ba}	0.06
Day 3	4.35 ± 0.04 ^{Aa}	4.33 ± 0.03 ^{Aa}	4.34 ± 0.04 ^{Aa}	4.41 ± 0.04 ^{Ba}	4.28 ± 0.03 ^{Aa}	0.06
Day 6	4.38 ± 0.04 ^{Aa}	4.25 ± 0.03 ^{Ba}	4.34 ± 0.04 ^{Aa}	4.25 ± 0.03 ^{Ba}	4.16 ± 0.03 ^{ca}	0.06
Day 9	ND	4.10 ± 0.04 ^{ca}	4.22 ± 0.04 ^{Ba}	4.27 ± 0.03 ^{Ba}	4.24 ± 0.04 ^{Ba}	0.06
F-value	2.11ns	28.7*	9.4*	11.2*	13.6*	—
Low Temperature (10±1°C) — Analysis every 5 days for 25 days						
Day 0	4.22 ± 0.04 ^{Aa}	4.29 ± 0.04 ^{Aa}	4.37 ± 0.04 ^{Aa}	4.27 ± 0.04 ^{Aa}	4.27 ± 0.04 ^{Aa}	0.08
Day 5	4.40 ± 0.05 ^{Ba}	4.27 ± 0.04 ^{Aa}	4.23 ± 0.04 ^{Aa}	4.24 ± 0.04 ^{Aa}	4.12 ± 0.03 ^{Ba}	0.08
Day 10	4.35 ± 0.05 ^{Aa}	4.27 ± 0.04 ^{Aa}	4.24 ± 0.04 ^{Aa}	4.13 ± 0.03 ^{Ba}	4.05 ± 0.03 ^{ca}	0.08
Day 15	4.49 ± 0.05 ^{Ba}	4.33 ± 0.04 ^{Aa}	4.28 ± 0.04 ^{Aa}	4.34 ± 0.04 ^{Aa}	4.45 ± 0.05 ^{Ba}	0.08
Day 20	4.39 ± 0.05 ^{Aa}	4.30 ± 0.04 ^{Aa}	4.36 ± 0.04 ^{Aa}	4.31 ± 0.04 ^{Aa}	4.43 ± 0.05 ^{Aa}	0.08
Day 25	4.43 ± 0.05 ^{Ba}	4.41 ± 0.04 ^{Aa}	4.45 ± 0.05 ^{Ba}	4.50 ± 0.05 ^{Ba}	4.56 ± 0.06 ^{ca}	0.08
F-value	6.8*	3.2*	4.1*	5.9*	8.7*	—

Means followed by different uppercase superscript letters in the same column differ significantly across storage days ($p \leq 0.05$). Means followed by different lowercase superscript letters in the same row differ significantly across $CaCl_2$ concentrations ($p \leq 0.05$). ND = not determined. * = significant ($p \leq 0.05$); ns = not significant.

At low temperature ($10 \pm 1^\circ\text{C}$), TTA values were generally higher than at ambient storage ranging from 0.25–0.51% versus 0.28–0.49% at ambient reflecting the slower organic acid catabolism under refrigerated conditions. Control fruits showed a marked decline from $0.51 \pm 0.03\%$ (day 0) to $0.25 \pm 0.02\%$ (day 15), with a slight recovery at day 20 and 25, likely due to residual microbial activity producing acids at later stages. $CaCl_2$ -treated fruits showed significant variation across storage days (F-values: 3.4–5.3, $p \leq 0.05$) but maintained higher mean TTA ($0.41 \pm 0.02\%$) than controls ($0.33 \pm 0.02\%$).

These findings are consistent with Tadewos *et al.* (2021), who attributed the higher acidity in $CaCl_2$ -treated tomatoes to inhibition of polygalacturonase an enzyme that contributes to acid catabolism during pectin degradation and with Bekele *et al.* (2022), who reported similar TTA preservation at low temperatures. As noted by Singh *et al.* (2018), declining TTA during storage reflects increasing ripeness; thus, the higher TTA maintained by $CaCl_2$ -treated fruits at both temperatures is indicative of effectively delayed ripening.

Total Soluble Solids (TSS)

Table 5 presents TSS values (°Brix) across treatments and storage days at both temperatures. At ambient temperature (28±1°C), control fruits showed a significant decline in TSS across storage days ($F = 4.29$, $p \leq 0.05$), ranging from $4.10 \pm 0.22^\circ\text{Brix}$ at day 0 to $3.70 \pm 0.18^\circ\text{Brix}$ at day 6. CaCl_2 -treated fruits displayed minimal and largely non-significant changes in TSS throughout storage (F-values: 0.51–1.04 ns), with values ranging from 3.50–3.90°Brix across all concentrations and days.

CaCl_2 -treated fruits generally had slightly lower TSS than controls, consistent with the delayed ripening mechanism: as ripening is slowed, the conversion of polysaccharides into soluble sugars is retarded, resulting in lower TSS (Mahajan *et al.*, 2020; Shehata *et al.*, 2021). None of the fruits at ambient temperature exceeded the 5°Brix processing suitability threshold (Osei *et al.*, 2018), suggesting the Burkina variety may have lower soluble solid content than processing-grade varieties grown under intensive cultivation.

Table 5: Effect of CaCl_2 concentration on total soluble solids (TSS, °Brix) of Burkina tomatoes stored at ambient (28±1°C) and low (10±1°C) temperatures (Mean ± SD).

Storage Day	CaCl ₂ Solution (% Concentration)					LSD (p ≤ 0.05)
Control (0%)	1.00%	1.50%	2.00%	2.50%		
Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD		
(°Brix)	(°Brix)	(°Brix)	(°Brix)	(°Brix)		
Ambient Temperature (28±1°C) — Analysis every 3 days for 9 days						
Day 0	4.10 ± 0.22 ^{Aa}	3.90 ± 0.20 ^{Aa}	3.90 ± 0.21 ^{Aa}	3.80 ± 0.19 ^{Aa}	3.75 ± 0.18 ^{Aa}	0.31
Day 3	3.90 ± 0.20 ^{Aa}	3.80 ± 0.19 ^{Aa}	3.70 ± 0.18 ^{Aa}	3.65 ± 0.18 ^{Aa}	3.60 ± 0.17 ^{Aa}	0.31
Day 6	3.70 ± 0.18 ^{Ba}	3.70 ± 0.18 ^{Aa}	3.65 ± 0.17 ^{Aa}	3.60 ± 0.17 ^{Aa}	3.55 ± 0.16 ^{Ba}	0.31
Day 9	ND	3.80 ± 0.19 ^{Aa}	3.60 ± 0.17 ^{Aa}	3.55 ± 0.17 ^{Aa}	3.50 ± 0.16 ^{Ba}	0.31
F-value	4.29*	0.51ns	0.83ns	0.62ns	1.04ns	—
Low Temperature (10±1°C) — Analysis every 5 days for 25 days						
Day 0	4.33 ± 0.24 ^{Aa}	4.07 ± 0.22 ^{Aa}	3.90 ± 0.20 ^{Aa}	3.80 ± 0.19 ^{Aa}	3.70 ± 0.18 ^{Aa}	0.29
Day 5	4.20 ± 0.23 ^{Aa}	4.00 ± 0.21 ^{Aa}	3.85 ± 0.20 ^{Aa}	3.75 ± 0.19 ^{Aa}	3.65 ± 0.18 ^{Aa}	0.29
Day 10	4.10 ± 0.22 ^{Aa}	3.95 ± 0.21 ^{Aa}	3.80 ± 0.20 ^{Aa}	3.70 ± 0.19 ^{Aa}	3.55 ± 0.17 ^{Ba}	0.29
Day 15	4.05 ± 0.22 ^{Aa}	3.88 ± 0.21 ^{Aa}	3.75 ± 0.19 ^{Aa}	3.65 ± 0.18 ^{Aa}	3.50 ± 0.17 ^{Ba}	0.29
Day 20	4.00 ± 0.21 ^{Aa}	3.80 ± 0.20 ^{Aa}	3.68 ± 0.18 ^{Aa}	3.58 ± 0.17 ^{Aa}	3.45 ± 0.16 ^{Ba}	0.29
Day 25	3.90 ± 0.20 ^{Ba}	3.72 ± 0.19 ^{Aa}	3.60 ± 0.18 ^{Aa}	3.50 ± 0.17 ^{Aa}	3.43 ± 0.16 ^{Ba}	0.29
F-value	3.71*	1.22ns	0.98ns	0.87ns	1.41ns	—

Means followed by different uppercase superscript letters in the same column differ significantly across storage days ($p \leq 0.05$). Means followed by different lowercase superscript letters in the same row differ significantly across CaCl_2 concentrations ($p \leq 0.05$). ND = not determined. * = significant ($p \leq 0.05$); ns = not significant. The 5°Brix processing suitability threshold is as reported by Osei *et al.* (2018).

At low temperature (10±1°C), control fruits showed a gradual and significant decline in TSS ($4.33 \pm 0.24^\circ\text{Brix}$ on day 0 to $3.90 \pm 0.20^\circ\text{Brix}$ on day 25; $F = 3.71$, $p \leq 0.05$), while CaCl_2 -treated fruits showed no significant TSS changes across the 25-day period (F-values: 0.87–1.41 ns) at any concentration. The TSS

range at low temperature (3.43–4.33°Brix) was slightly higher than at ambient temperature (3.50–4.10°Brix), reflecting the slower rate of soluble solid loss under refrigeration.

These results confirm that CaCl_2 has little direct effect on soluble sugar content at either storage temperature, a finding consistent with calcium postharvest studies by Sabir and Sabir (2020), Mahajan *et al.* (2020), and tomato-specific studies by Hailemichael *et al.* (2021) and Girmay *et al.* (2023). The 50–65% proportion of TSS attributable to glucose and fructose significantly influences organoleptic quality and consumer acceptability of tomatoes (Adedeji *et al.*, 2017); the maintenance of TSS within acceptable ranges across the CaCl_2 -treated groups therefore supports the quality fitness of treated fruits for fresh market consumption throughout the storage periods studied.

CONCLUSION

This study demonstrated that postharvest CaCl_2 dip treatment is a simple, affordable, and effective strategy for preserving the physicochemical quality of Burkina variety tomatoes, the predominant commercial cultivar in Ghana under both ambient ($28 \pm 1^\circ\text{C}$) and low ($10 \pm 1^\circ\text{C}$) storage conditions. CaCl_2 treatment significantly reduced physiological weight loss at ambient temperature (mean: $3.46 \pm 0.41\%$ treated vs $8.01 \pm 0.78\%$ control) and at low temperature ($0.97 \pm 0.14\%$ vs $22.93 \pm 2.11\%$), maintained higher total titratable acidity indicative of delayed ripening, and better preserved moisture content particularly at higher concentrations. The 1.50% CaCl_2 concentration was optimal at ambient temperature for minimising weight loss, while all CaCl_2 concentrations were effective at low temperature throughout the 25-day storage period. TSS was not significantly altered by CaCl_2 treatment at either storage temperature, though control fruits showed significant TSS decline over time. The combination of low-temperature storage with CaCl_2 concentration solution treatment provided the greatest overall shelf-life extension and quality preservation.

These findings are of direct practical relevance to Ghanaian smallholder farmers and market traders operating with limited or inconsistent cold chain access. Future research should investigate the effects of CaCl_2 on tomato nutritional quality parameters (lycopene, ascorbic acid), explore combined treatments with other food-grade coatings (e.g., chitosan, aloe vera gel), assess the impact of CaCl_2 application method (vacuum infiltration versus dipping), and evaluate economic feasibility at the smallholder farm level to inform scalable postharvest management protocols for the Ghanaian tomato industry.

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DECLARATION OF CONFLICT OF INTEREST

The author declares no conflict of interest.

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