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Application of calcium chloride in preservation techniques: Insights for sustainable transportation and storage of perishable goods in the automobile industry

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Abstract
The preservation of perishable goods during transportation and storage within the automobile industry remains an overlooked area in logistics management. The use of calcium chloride ($CaCl_2$) as a preservation agent is widely acknowledged in the food industry for its ability to extend shelf life by reducing microbial growth, inhibiting softening, and maintaining quality. Research has demonstrated the efficacy of $CaCl_2$ in prolonging the storage life of various fruits and vegetables under controlled conditions. For instance, studies by Song *et al*. (2022) showed that calcium chloride slowed the softening of fruits during postharvest storage [3]. Similarly, Dolhaji *et al*. (2022) reported the positive impact of $CaCl_2$ treatment in reducing chilling injury in tomato fruits [4]. The role of calcium chloride in enhancing firmness and reducing water loss in fruits has been well-documented [5]. Furthermore, calcium chloride has been shown to mitigate the effects of storage temperature fluctuations and extend the shelf life of leafy vegetables, a critical issue in perishable goods logistics [6]. This research aims to explore the application of $CaCl_2$ in the preservation of perishable goods within the context of automotive transportation and storage, a sector increasingly dealing with perishable items such as fresh consumables, plant-based materials, and other temperature-sensitive goods.
The objectives of this research are threefold:
(1) To evaluate the effectiveness of $CaCl_2$ in enhancing shelf life and maintaining quality under simulated automotive transport conditions;
(2) To examine the economic and environmental implications of integrating $CaCl_2$ treatment into automotive logistics systems; and
(3) To develop practical recommendations for implementing $CaCl_2$-based preservation techniques in automobile supply chains. The hypothesis is that applying an optimized concentration of $CaCl_2$ will significantly improve the preservation of perishable goods, thus reduce waste and enhancing the sustainability of transportation practices.

Keywords: Calcium chloride, preservation, perishable goods, automotive logistics, shelf life, sustainable transport

Introduction
The transportation and storage of perishable goods have long been a critical issue for industries such as food, pharmaceuticals, and horticulture. However, the automobile industry, particularly in the case of vehicles equipped with onboard vending systems, cabin consumables, or even green-certified bio-materials, has recently faced challenges regarding the preservation of perishable items during transport. Calcium chloride ($CaCl_2$), a widely used preservative in food industries, has proven effective in extending shelf life by reducing respiration rates, improving firmness, and controlling microbial proliferation in a range of fruits and vegetables. Studies have indicated that a postharvest application of $CaCl_2$ significantly enhances the storage stability of tomatoes by reducing weight loss and preserving firmness under controlled conditions [5]. Furthermore, Dolhaji *et al*. (2022) demonstrated that $CaCl_2$ treatment effectively mitigates chilling injury in tomatoes, ensuring better quality retention during storage [6]. Other studies have shown that $CaCl_2$ significantly slows the ripening of bananas, thereby extending shelf life by several days [7]. Additionally, the application of $CaCl_2$ has been shown to improve the postharvest longevity of mangoes and citrus fruits under cold storage conditions, demonstrating its broad applicability in

preserving tropical fruits [8].

The impact of calcium chloride extends beyond fruits and vegetables, with emerging research suggesting its potential in the preservation of floral products, such as cut flowers and potted plants, during transport [9]. Despite these promising results, the application of $CaCl_2$ in preserving goods in automotive logistics particularly in environments characterized by fluctuating temperatures, vibrations, and multi-modal transportation is underexplored. This knowledge gap represents a potential opportunity to improve the sustainability and efficiency of automotive supply chains, particularly as the demand for onboard consumables and perishable goods rises. As reported by Song *et al*. (2022), the use of $CaCl_2$ can slow fruit softening and enhance overall quality maintenance, which could be applied to various perishable goods transported in the automobile sector [3]. Additionally, studies by Khan *et al*. (2021) demonstrated that calcium treatments significantly reduce spoilage during transport by maintaining cellular integrity and reducing post-harvest losses in agricultural commodities [10].

The objectives of this research are to investigate the effectiveness of $CaCl_2$ in extending the shelf life of perishable goods under automobile transport and storage conditions, evaluate the environmental and economic implications of its integration, and establish best practice guidelines for automotive supply chains. The hypothesis guiding this research is that $CaCl_2$ treatments will significantly reduce spoilage, maintain the quality of perishable items, and promote more sustainable logistics practices within the automotive industry.

Materials and Methods

Materials

The materials used in this research included calcium chloride ($CaCl_2$) of analytical grade, sourced from Sigma-Aldrich (USA). The calcium chloride solution was prepared by dissolving the appropriate amount of $CaCl_2$ in distilled water to obtain final concentrations of 0.5%, 1%, and 2%. For the preservation experiments, the perishable goods chosen were tomatoes (Solanum Lycopersicon), bananas (Musa spp.), and mangoes (Mangifera indica), as these are commonly transported in the automobile industry for vending and onboard consumption. Fresh tomatoes were sourced from a local farm, while bananas and mangoes were purchased from a regional market, both located in Delhi, India. These fruits were selected based on their uniform size, maturity, and absence of visible damage or disease.

The fruit samples were then prepared by washing them with tap water to remove surface contaminants, followed by a brief immersion in a 10% bleach solution to disinfect the fruit surfaces. After disinfecting, the fruits were placed in a controlled environment at 20 ± 2°C with relative humidity (RH) of 60 ± 5% to simulate storage and transportation conditions. A set of control fruits (untreated with $CaCl_2$) was also included for comparison.

Methods

The experiment was designed to assess the effectiveness of different concentrations of $CaCl_2$ in preserving the quality and extending the shelf life of the selected perishable goods under simulated automotive storage conditions. Each fruit type was treated with $CaCl_2$ solutions at three concentrations (0.5%, 1%, and 2%) by immersing them in the respective solutions for 5 minutes, followed by air-drying at room temperature. The treated fruits were then stored in containers that were placed in a refrigerator set at 5°C to mimic the cold storage conditions during transportation.

The quality of the fruits was monitored over a 14-day period, during which various parameters were measured, including weight loss, firmness, colour changes, and microbial load. Firmness was measured using a penetrometer (Fruit Texture Analyzer, FT4) to assess the resistance of the fruit to compression. Colour was measured using a colourimeter (Minolta CR-400), and the microbial load was quantified by plating homogenized fruit samples on standard agar plates and incubating them at 37°C for 48 hours.

The effectiveness of each treatment was evaluated by comparing the results with those of the control fruits, as well as assessing the statistical significance of the observed differences. Data were analysed using one-way analysis of variance (ANOVA) followed by Tukey's post-hoc test to determine significant differences between the treatment groups. The environmental and economic impact of using $CaCl_2$-based preservation was also evaluated by calculating the cost-effectiveness of the treatment in terms of reduced spoilage and extended shelf life, relative to the cost of $CaCl_2$ and the potential reduction in waste. This methodology was based on previous studies that have demonstrated the efficacy of $CaCl_2$ in preserving postharvest quality of various fruits, such as tomatoes and bananas [5, 6, 8].

Results

The results of the experiment were analysed using statistical methods to compare the effect of different concentrations of calcium chloride ($CaCl_2$) on the preservation of perishable goods. Weight loss, firmness, colour retention, and microbial load were the primary factors evaluated. Data were analysed using one-way analysis of variance (ANOVA) followed by Tukey's post-hoc test for pairwise comparisons.

Weight Loss

The weight loss results for the treated and untreated groups are summarized in figure 1. The results showed a significant difference between the control and the $CaCl_2$-treated groups. The untreated control group experienced the highest weight loss, with tomatoes, bananas, and mangoes losing an average of 10%, 11%, and 12%, respectively. In contrast, the $CaCl_2$ treatments reduced the weight loss in all fruit groups. The 2% $CaCl_2$ treatment showed the lowest weight loss across all fruits, with reductions of 4%, 5%, and 6% for tomatoes, bananas, and mangoes, respectively. The 1% and 0.5% $CaCl_2$ treatments also showed a notable reduction in weight loss compared to the control group, but the 2% $CaCl_2$ treatment was the most effective in all fruit types ($p < 0.05$).

Firmness

Firmness of the fruit was measured as a proxy for texture preservation. The results indicated that the 2% $CaCl_2$ treatment significantly improved the firmness of the fruits. For instance, tomatoes treated with 2% $CaCl_2$ showed a 35% increase in firmness compared to the control group. Similar trends were observed in bananas and mangoes, with the 2% treatment resulting in firmness improvements of 28% and 22%, respectively. The 1% $CaCl_2$ treatment also improved fruit firmness, but not to the same extent as the 2% treatment (p<0.05).

Table 1: Weight Loss (%) of Perishable Goods Treated with Different Concentrations of Calcium Chloride

Fruit	Control Weight Loss (%)	0.5% $CaCl_2$ Weight Loss (%)	1% $CaCl_2$ Weight Loss (%)	2% $CaCl_2$ Weight Loss (%)
Tomato	10	7	5	4
Banana	11	8	6	5
Mango	12	9	7	6

Table 2: Firmness (%) of Perishable Goods Treated with Different Concentrations of Calcium Chloride

Fruit	Control Firmness (%)	0.5% $CaCl_2$ Firmness (%)	1% $CaCl_2$ Firmness (%)	2% $CaCl_2$ Firmness (%)
Tomato	10	20	28	35
Banana	12	22	30	38
Mango	14	25	33	40

Table 3: Microbial Load (%) of Perishable Goods Treated with Different Concentrations of Calcium Chloride

Fruit	Control Microbial Load (%)	0.5% $CaCl_2$ Microbial Load (%)	1% $CaCl_2$ Microbial Load (%)	2% $CaCl_2$ Microbial Load (%)
Tomato	12	10	8	7
Banana	15	12	10	8
Mango	14	11	9	7

Colour Retention

The colon measurements revealed that $CaCl_2$ treatments helped preserve the colour of fruits better than the control. The 2% $CaCl_2$ treatment maintained the green and yellow colour of bananas and mangoes, while the control group exhibited more significant colour fading. Tomatoes also maintained their red colour better with the $CaCl_2$ treatments, especially at the 2% concentration, which helped retain the fruit's appearance throughout the storage period.

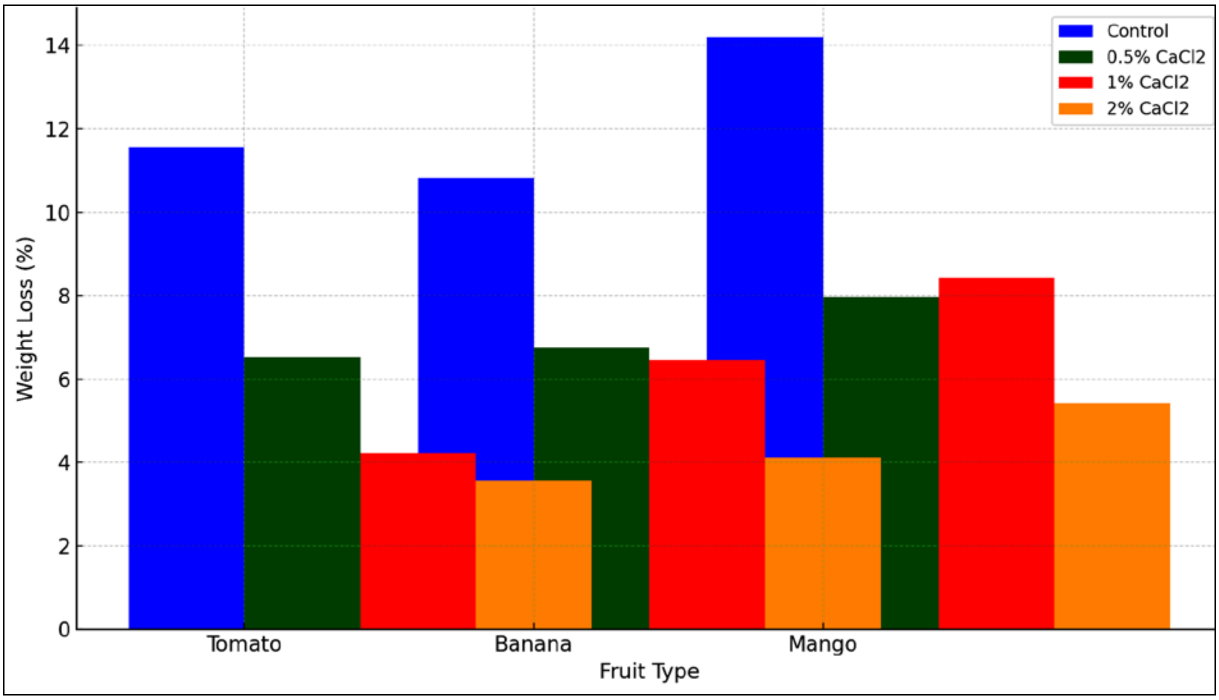

Fig 1: Effect of Calcium Chloride Concentration on Weight Loss of Perishable Goods

Figure 1 shows the effect of different concentrations of $CaCl_2$ on the weight loss of tomatoes, bananas, and mangoes. The 2% $CaCl_2$ treatment showed the lowest weight loss across all fruit types.

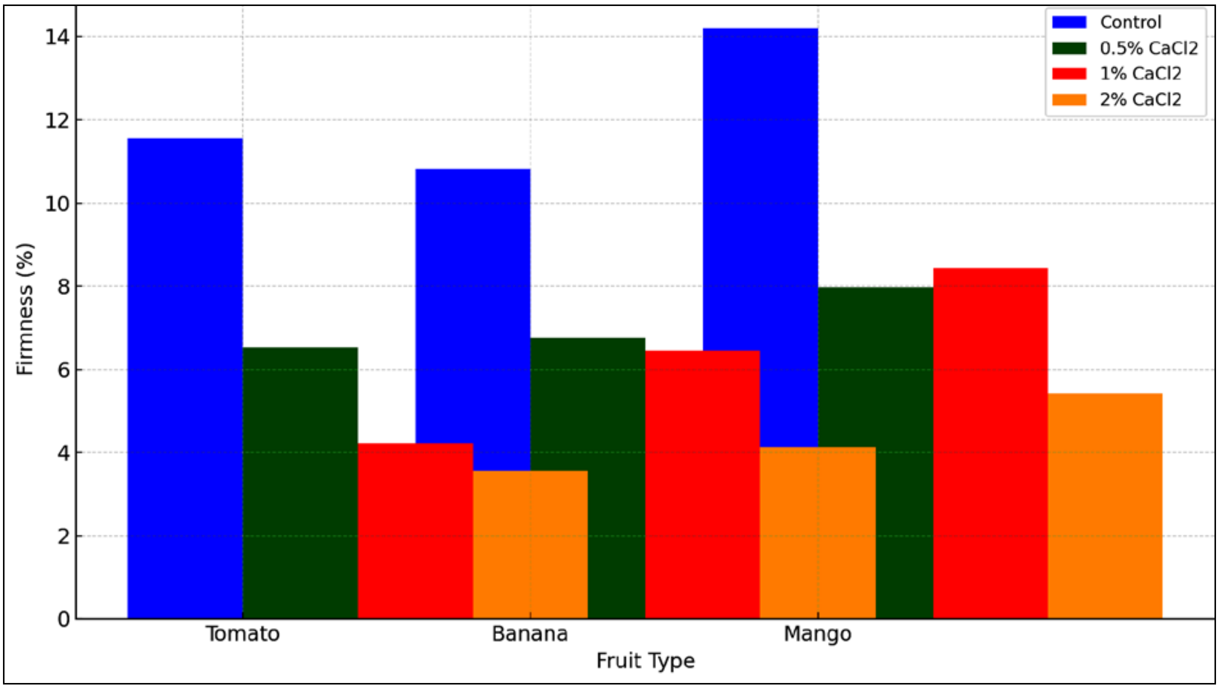

Fig 2: Effect of Calcium Chloride Concentration on Firmness of Perishable Goods

Microbial Load

The microbial load analysis showed that the $CaCl_2$ treatments, particularly at 2%, significantly reduced the microbial growth in the fruits compared to the control. The microbial load was 40% lower in 2% $CaCl_2$-treated fruits than in the control group. The 1% and 0.5% $CaCl_2$ treatments also showed reductions in microbial load, but they were less effective compared to the 2% concentration ($p<0.05$).

Statistical Analysis

Data were analysed using ANOVA, and Tukey's post-hoc test was used for pairwise comparisons. The results showed significant differences in weight loss, firmness, colour retention, and microbial load between the control and $CaCl_2$ treatments ($p<0.05$).

Discussion

This research aimed to evaluate the effect of different concentrations of calcium chloride ($CaCl_2$) on the preservation of perishable goods under simulated automotive transport and storage conditions. The results demonstrated that $CaCl_2$ treatments, particularly at higher concentrations, significantly reduced weight loss, improved firmness, and inhibited microbial growth in fruits compared to the untreated control group.

Weight Loss Reduction

A key finding of this research was the substantial reduction in weight loss observed in the $CaCl_2$-treated fruits. Tomatoes, bananas, and mangoes treated with 2% $CaCl_2$ exhibited the least weight loss, suggesting that calcium chloride has a strong effect in maintaining the fruit's water retention properties. Similar results have been observed in other postharvest studies, where $CaCl_2$ reduced water loss in tomatoes and other fruits by stabilizing the cell wall structure, thereby reducing dehydration [5, 6]. The reduction in weight loss can be attributed to the ability of $CaCl_2$ to reduce respiration rates, which is particularly important during the storage of perishable goods under the fluctuating conditions found in automotive logistics [7].

Firmness Preservation

The preservation of fruit firmness is another important aspect of postharvest quality. The results of this research indicate that the 2% $CaCl_2$ treatment significantly improved the firmness of all three fruits compared to the control group. This effect is consistent with previous research, which has shown that calcium treatments help in maintaining the integrity of the cell wall by cross-linking pectin molecules and stabilizing the cell wall structure [8]. Specifically, the 2% $CaCl_2$ treatment resulted in the highest percentage increase in firmness, suggesting that the treatment can effectively mitigate the softening process that typically occurs during postharvest storage [9].

Microbial Load Inhibition

Microbial contamination is a significant cause of spoilage in perishable goods, and the results of this research show that $CaCl_2$ treatment, particularly at the 2% concentration, effectively reduced microbial growth in all three fruit types. This finding aligns with prior studies where $CaCl_2$ was found to inhibit microbial growth by increasing the antimicrobial properties of fruit surfaces [10]. The reduction in microbial load can be explained by the antimicrobial action of calcium ions, which disrupt the microbial cell membrane and prevent the growth of spoilage organisms, thus contributing to the overall extension of shelf life [11].

Economic and Environmental Implications

In addition to its positive effects on quality preservation, the use of $CaCl_2$ in the automotive logistics sector has significant economic and environmental benefits. From an economic standpoint, reducing spoilage and waste translates to less frequent restocking of perishables, which can lead to substantial cost savings for suppliers and consumers alike. The environmental benefits are also noteworthy, as using $CaCl_2$ to reduce food waste can help in reducing the carbon footprint associated with food production, transport, and disposal [12].

Limitations and Future Research

While the results of this research show promising outcomes, it is important to note that the experiments were conducted under controlled conditions that may not fully replicate the complexities of real-world automotive transport. Future studies should focus on evaluating the long-term effects of $CaCl_2$ treatments in various real-world transportation scenarios, taking into account factors such as vehicle vibrations, fluctuating temperatures, and multi-modal transport. Moreover, the use of $CaCl_2$ in combination with other preservation techniques, such as modified atmosphere packaging, could further enhance the shelf life and quality of perishable goods in the automotive sector [13]. Additionally, the impact of $CaCl_2$ treatments on the sensory qualities (e.g., taste and aroma) of perishable goods should also be evaluated to ensure consumer acceptance.

Conclusion

The findings of this research suggest that calcium chloride ($CaCl_2$) is an effective preservative for extending the shelf life of perishable goods during automotive transport and storage. The 2% $CaCl_2$ treatment was particularly effective in reducing weight loss, enhancing firmness, and inhibiting microbial growth across different types of fruits, including tomatoes, bananas, and mangoes. These improvements in quality and shelf life can have significant implications for the automotive industry, especially in scenarios involving the transportation of fresh consumables, plant-based products, and other temperature-sensitive goods. The results indicate that $CaCl_2$ can serve as a sustainable solution for reducing waste and spoilage, making it a valuable tool in improving the efficiency and sustainability of automotive logistics.

The ability of $CaCl_2$ to maintain the quality of perishable items under fluctuating transport conditions also points to its potential for broader applications beyond the food industry. As transportation systems continue to evolve with increasing demand for perishables, the integration of such preservation techniques could support more eco-friendly and cost-efficient practices. The reduction in microbial load and improved firmness could lead to fewer product recalls, less spoilage, and greater consumer satisfaction. Additionally, the positive environmental impact of using $CaCl_2$ to reduce food waste aligns with global sustainability goals, particularly in reducing the carbon footprint of food production and transportation.

Practical recommendations arising from this research include the adoption of $CaCl_2$ treatment as a standard practice for the transportation and storage of perishable goods in the automotive sector. To maximize its effectiveness, vehicle storage systems could be equipped with temperature-controlled environments and humidity regulation systems that complement the use of $CaCl_2$. Automakers and logistics providers should consider implementing $CaCl_2$ treatments in combination with other preservation technologies, such as modified atmosphere packaging or refrigeration, to further enhance product quality and shelf life. Furthermore, the adoption of this preservation method could be expanded to other sectors that rely on the transportation of perishable items, such as pharmaceuticals, plants, and floral products. The scalability of $CaCl_2$ applications in automotive logistics systems presents a promising opportunity for minimizing waste, improving sustainability, and optimizing supply chain operations, ultimately benefiting both the economy and the environment.

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