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TECHNICAL REPORT

Fish Pond Storage Preserves Chili Puree, but Nitrogen Flow-Through Fails: Unravelling the Mechanism

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Abstract: Perishable food preservation in rural and resource-limited settings remains a significant challenge, as conventional techniques frequently depend on synthetic additives or energy-intensive processes incompatible with green chemistry principles. This study evaluated fish pond immersion as a novel, low-cost preservation method for freshly ground chili purée, investigating its efficacy with and without continuous nitrogen gas flow. Chili purée samples were packaged in sealed plastic containers and assigned to two treatment conditions: direct pond immersion and pond immersion with nitrogen flow-through simulating modified atmosphere storage. Quality parameters, including pH, moisture content, color, microbial count, and sensory attributes, were monitored at weekly intervals over a four-week storage period. Nitrogen flow-through storage proved ineffective, with samples exhibiting accelerated microbial growth and more rapid deterioration in sensory quality compared to controls. In contrast, samples stored by direct pond immersion without nitrogen demonstrated superior stability across all quality indicators throughout the storage period. These findings indicate that the preservative effect of fish pond storage is not attributable to nitrogen gas alone, but is likely mediated by physico-chemical and ecological characteristics of the pond environment. Further investigation is warranted to identify the specific mechanisms involved and to optimize fish pond storage as a scalable, sustainable food preservation strategy for short-term applications in low-resource contexts.

Keywords: Chili purée, Food preservation, Fish pond storage, Modified atmosphere, Microbial spoilage, Green chemistry, Sensory quality, Low-technology preservation

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Introduction

Chili (*Capsicum annuum* L.) is one of the most important horticultural commodities in tropical countries, including Indonesia, due to its high consumption, economic value, and cultural significance [1, 2]. Chili contributes substantially to household diets as a daily cooking spice and vegetable ingredient, while also serving as a raw material for food industries, a source of export commodities, and a generator of employment opportunities [3]. Its nutritional content, particularly vitamin C and bioactive compounds such as capsaicin, further enhances its value in both food and health sectors [4]. Given this multifaceted importance, chili is regarded as a strategic agricultural product with direct implications for food security and rural

economic sustainability [5]. Despite its economic and nutritional significance, chili is highly perishable and prone to rapid quality degradation [6].

In tropical environments such as Indonesia, high ambient temperatures and fluctuating relative humidity accelerate respiration and transpiration rates, resulting in wilting, microbial growth, and spoilage [5, 6]. These postharvest losses pose a serious problem for farmers, distributors, and consumers, with significant economic consequences across the supply chain [7, 8]. Conventional storage technologies, such as refrigeration at temperatures below 10 °C with high relative humidity, can effectively slow down deterioration. However, such technologies are often energy-intensive, costly, and not always accessible in rural or resource-limited settings. Similarly, advanced techniques such as modified atmosphere packaging (MAP) and the use of chemical preservatives have been widely investigated, but these approaches also raise concerns regarding cost, sustainability, and consumer acceptance.

To address these challenges, alternative preservation strategies that are both low-cost and environmentally sustainable have attracted increasing attention. One such approach is the conversion of chili into fresh-ground puree, which offers advantages in terms of ease of use, reduced handling, and extended usability in household and industrial applications. Recent studies have reported that fresh-ground chili puree stored in sealed plastic containers and immersed in fish ponds can maintain stability for up to four months [9-11]. This surprising preservation effect suggests that aquatic environments may provide natural cooling and atmospheric modifications that inhibit microbial growth and biochemical degradation. Such findings align with the broader search for green preservation technologies that minimize reliance on external energy inputs and synthetic additives. A key hypothesis emerging from previous observations is that pond-based storage may create modified atmospheric conditions inside the packaging, possibly through the diffusion of inert gases such as nitrogen. Nitrogen is commonly employed in food preservation to displace oxygen, inhibit oxidative reactions, and suppress aerobic microbial activity (Fig. 1). However, whether the prolonged stability of pond-stored chili puree is truly attributable to nitrogen ingress from the pond environment has not been empirically validated. Understanding this mechanism is critical, as it may provide a scientific basis for developing scalable, eco-friendly preservation methods tailored to tropical, resource-limited contexts. Therefore, this study aimed to evaluate the role of nitrogen gas in pond-based chili puree storage by simulating nitrogen flushing in sealed containers immersed in fish ponds. By comparing the quality attributes of chili puree under two storage conditions, direct immersion without nitrogen and immersion with continuous nitrogen flow. This research seeks to clarify whether nitrogen gas contributes to the observed preservation effect. The findings are expected to advance knowledge on low-tech, green storage systems and provide insights for the development of sustainable preservation technologies in line with green chemistry and food security objectives.

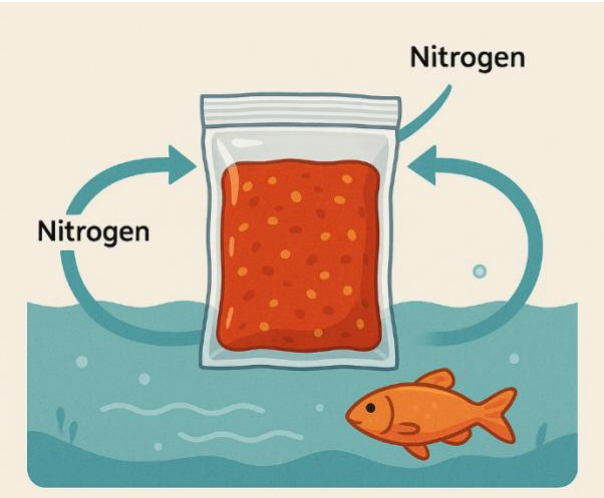

Fig. 1: The cycle of nitrogen formation for preserve the fresh puree ground chili in the fish pond

Material and Methods

Fresh chilies were first washed thoroughly under running water to remove dirt and surface impurities. The cleaned chilies were then ground using a laboratory grinder until a homogeneous puree was obtained, followed by the addition of sodium

chloride (NaCl) at a concentration of 15% (w/w) to act as a preservative. A total of 100 g of the prepared chili puree was placed into Polypropylene (PP) plastic packaging and tightly sealed using a plastic clip [12]. This packaged sample was subsequently immersed directly in a fish pond, serving as the control treatment. For the modified atmosphere packaging (MAP) treatment, 100 g of chili puree was placed into an open container, which was then positioned inside a custom-made acrylic chamber. The chamber was continuously supplied with nitrogen gas (N_2) through a flow-through system to simulate a modified atmosphere condition. After establishing the nitrogen environment, the entire chamber was immersed in the same fish pond as the control samples, ensuring identical environmental conditions except for the presence of nitrogen gas. The experimental setup for both treatments is illustrated in Fig. 2. Both control and MAP-treated samples were stored in the pond for one week. Quality evaluations of the chili puree were conducted at regular intervals during storage. The parameters analyzed included water content, color characteristics, total titratable acidity, microbial load (plate count), and pH. These indicators were selected to assess the physicochemical stability, microbial safety, and overall quality of the product under the two preservation conditions.

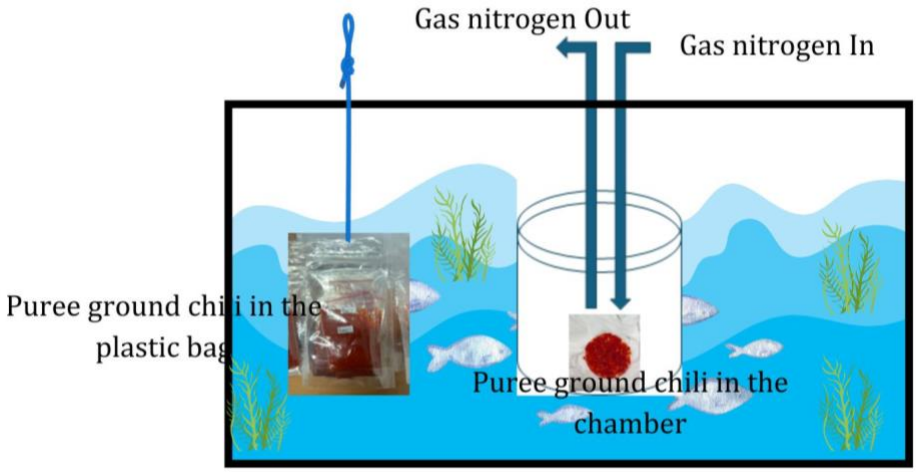

Fig. 2: The illustration of experimental design for fish pond storage

Water content analysis was carried out using the gravimetric method, color analysis was carried out by measuring using a hunter lab tool, total acid analysis was carried out using the titration method, total plate count analysis was carried out by culturing total microbes on plate count agar media, and pH analysis was carried out using a pH meter [12-15]. All experiments were conducted in triplicate.

Results and Discussion

Table 1 summarizes the initial characteristics of the fresh-ground chili puree, which provide essential baseline information for interpreting subsequent storage dynamics. The puree exhibited high moisture, a condition widely recognized as a major contributor to the perishability of fresh horticultural commodities [16, 17]. Elevated water content not only promotes enzymatic activity but also creates a favorable medium for microbial growth, thereby reducing shelf stability. These characteristic underscores the inherent challenge of maintaining the quality of chili-based products without effective preservation. From a visual standpoint, the puree showed a vivid red coloration, strongly influenced by carotenoid pigments such as capsanthin and capsorubin. These pigments are highly sensitive to environmental stressors including light, oxygen, and microbial metabolites. The subsequent decline in color intensity during storage, particularly in samples exposed to nitrogen flushing, suggests that pigment degradation was exacerbated under conditions that lacked the stabilizing influence of the pond environment. This observation indicates that pond immersion may provide a moderating effect by reducing oxidative stress or through interactions with dissolved compounds in the aquatic medium.

The initial acidity and pH values reflected a condition that, while containing organic acids, was still close to neutral. Such conditions are known to provide limited inhibition of microbial growth, as most spoilage microorganisms can thrive in near-neutral environments. The tendency of nitrogen-flushed samples to shift toward greater acidity during storage points to active

microbial fermentation, whereas the more stable acid-base balance in pond-immersed samples suggests the presence of natural buffering or inhibitory factors in the pond ecosystem. Microbiological analysis revealed a moderate initial microbial load, consistent with minimally processed fresh products. This starting population served as a reservoir for subsequent proliferation. However, growth patterns differed markedly between treatments: microbial counts increased rapidly in nitrogen-flushed samples but rose more gradually under pond immersion. This suggests that the pond environment may exert antimicrobial effects, possibly through dissolved gases such as carbon dioxide, or through the presence of natural metabolites like ammonia or humic substances that create suboptimal conditions for microbial proliferation. Taken together, these baseline characteristics highlight the intrinsic vulnerability of fresh-ground chili puree to rapid deterioration due to its high-water content, near-neutral pH, and initial microbial load. They also contextualize the observed differences during storage, where pond immersion appeared to mitigate quality degradation more effectively than nitrogen flushing. The comparative analysis thus reinforces the idea that ecological and physico-chemical interactions in pond environments can provide protective functions that extend beyond simple temperature regulation, offering a promising low-tech alternative for short-term preservation of perishable commodities [18].

Table 1: Quality parameter of fresh-ground chili puree

Parameters	Results (%)
Water content	74,71 ± 0,61
Colour °Hue	204,30 ±0,31
pH	6,1 ± 0,00
Total Acid	11,25 ± 0,00
ALT	$3,8 \times 10^2 \pm 10.20$ CFU

Figure 3 shows the changes in the quality parameters of fresh-ground chili puree stored in a fish pond with plastic treatment and in a chamber filled with nitrogen gas. In general, it can be seen that in storage with nitrogen gas flowing through the system, the quality of fresh-ground chili puree is different from that of chili puree stored in plastic. The water content, total acid, and total microbes increased (3A, 3C, and 3D), while the pH and color intensity decreased (3B and 3C). This trend contrasts with the storage of fresh-ground chili puree in plastic and soaked in a fish pond (control treatment). In the control, the values of all parameters—water content, color, pH, total acid, and total plate count, remained close to the initial conditions, indicating better quality retention. These results demonstrate that storing fresh-ground chili puree in a chamber with nitrogen gas flow cannot preserve its quality. Mechanistically, the continuous nitrogen flushing likely accelerated the evaporation of free water at the puree surface due to gas flow dynamics, leading to partial dehydration in the first week. This surface drying may have increased heterogeneity in water activity (aw), creating microenvironments favorable for microbial colonization. Moreover, while nitrogen is generally used to suppress aerobic spoilage organisms, the complete removal of oxygen created strictly anaerobic conditions. Under these conditions, facultative and obligate anaerobes such as lactic acid bacteria and certain spoilage Clostridium species could proliferate, resulting in increased acid production, decreased pH, and eventual tissue breakdown. The combination of moisture imbalance, altered microbial ecology, and enzymatic activity explains the observed rotting after two weeks of storage. Rotting, as described in previous studies, represents the biochemical and microbial transformation of food from its normal state to an undesirable, degraded condition [19, 20].

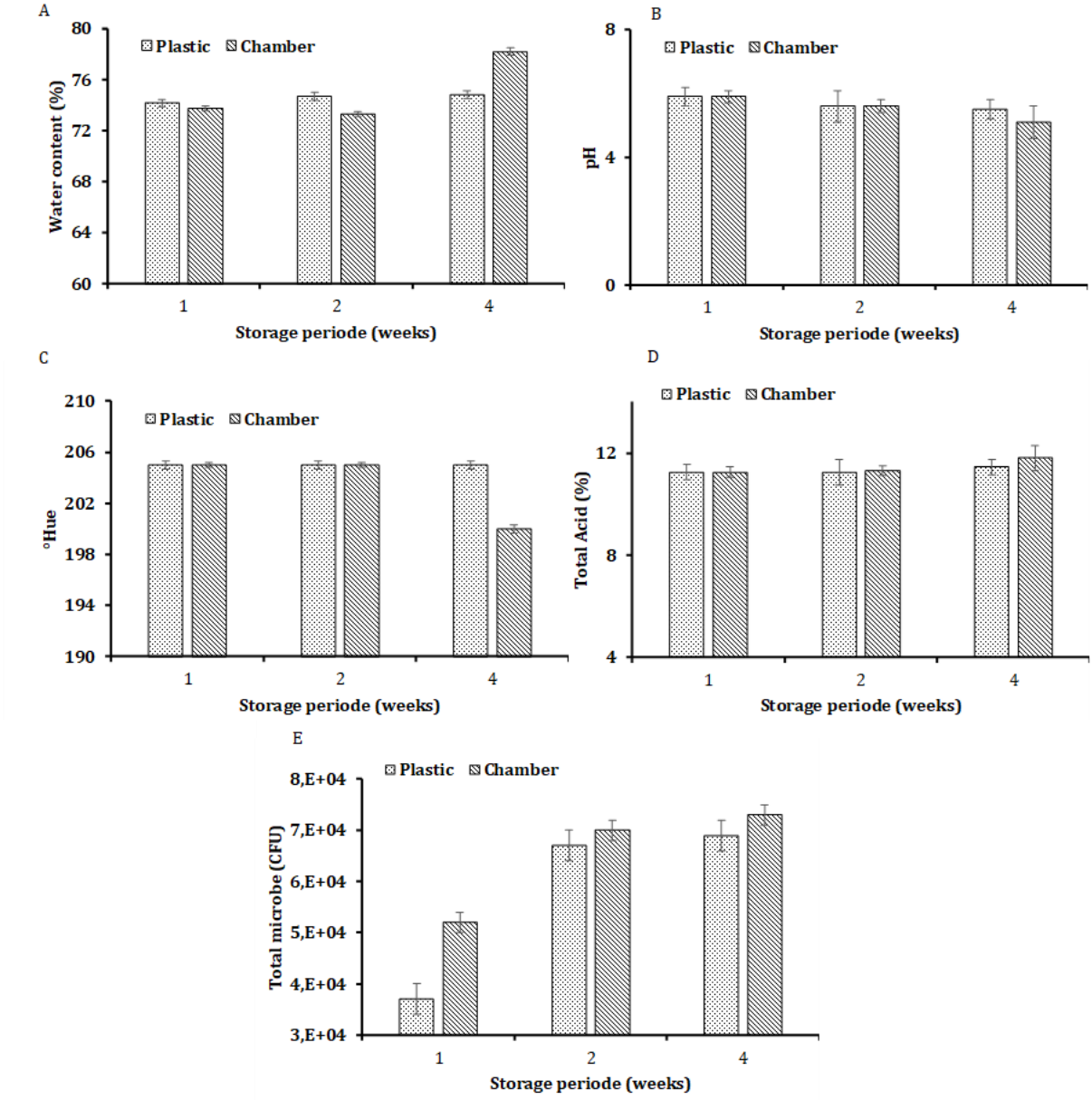

Fig. 3: Observation data of fish pond storage of puree fresh ground chili with Nitrogen flow through and plastic bag treatments (A; water content, B; pH, C; °Hue, D; total acid and E; total microbes)

Noticeable differences in spoilage patterns are observed when fresh ground chili puree is stored at room temperature without the additional storage treatment involving immersion in a fish pond (Fig. 4). Under room temperature conditions, significant changes in key quality indicators occur within a relatively short period. Specifically, the total acid value shows a sharp increase, while the pH decreases considerably over the span of four weeks. This rapid shift in acidity is a strong indicator of intense fermentation activity, which is typically driven by microbial growth. Moreover, the microbial count in the chili puree stored at room temperature becomes extremely high, reaching levels classified as "too numerous to count" (TNTC). This result indicates uncontrolled microbial proliferation, which is a common sign of spoilage in perishable food products. The rapid microbial growth further accelerates fermentation, contributing to changes in texture, flavor, and overall product quality [21]. In contrast, the chili puree stored in plastic and submerged in the fish pond exhibits a remarkably slower rate of spoilage. This stark difference highlights the presence of a preservation mechanism within the pond storage environment that effectively delays microbial growth and associated biochemical changes.

The contrasting outcomes between the two storage methods strongly suggest that certain conditions in the fish pond, possibly related to gas composition, temperature stability, or microbial competition, contribute to extending the shelf life of the chili puree. Further investigation is necessary to pinpoint the exact factors responsible for this preservation effect, which could offer valuable insights for developing natural and cost-effective food preservation techniques.

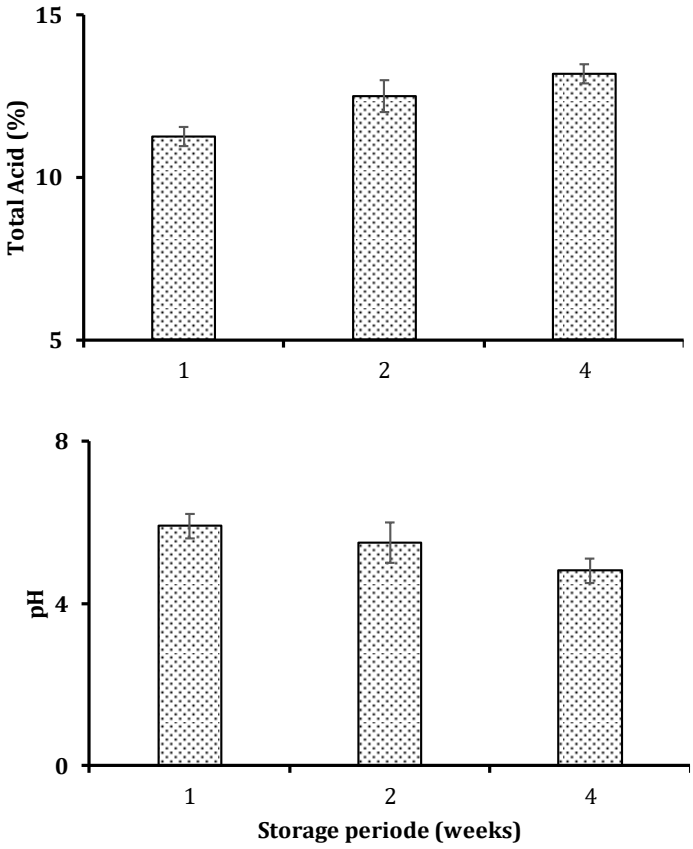

Fig. 4: Changes in pH and total titratable acidity of fresh ground chili puree during storage at room temperature

The preservation process observed in fresh ground chili puree stored in plastic has been hypothesized to result from the formation of an inert system within the ecosystem of the fish pond. This inert system is believed to occur due to the presence of specific gases within the pond environment. These gases are thought to penetrate the plastic packaging and gradually replace the oxygen inside the container. As the oxygen concentration decreases, the internal atmosphere becomes inert, creating conditions that inhibit the activity of enzymes responsible for the degradation of the chili puree. Since enzymatic activity plays a crucial role in initiating fermentation and subsequent spoilage, this inert environment is presumed to slow down the decay process [22].

However, this hypothesis has certain limitations. In theory, nitrogen gas, which is often cited as the primary inert gas in such systems, is widely used in controlled atmosphere storage and modified atmosphere packaging techniques to prolong the shelf life of perishable products [23-25]. These methods work by replacing oxygen with nitrogen to reduce oxidative reactions and microbial growth. Despite this theoretical basis, the application of nitrogen gas alone in this study did not appear to significantly delay the spoilage process of fresh ground chili puree. This discrepancy suggests that additional factors may be at play in the preservation mechanism within the fish pond environment. The prolonged shelf life of the chili puree, reportedly lasting more than two months and potentially up to six months, as observed by local farmers, indicates that there may be other contributing variables. These could include unique microbial interactions, specific gas compositions in the pond ecosystem, or even environmental factors such as temperature stability and water pressure. Further research is necessary to identify the exact mechanisms involved in this preservation phenomenon. Understanding these factors could provide valuable insights into developing alternative, natural preservation methods for agricultural products.

Conclusion

From this study, it can be concluded that storing fresh ground chili puree in a fish pond effectively extends its shelf life, maintaining quality for at least one month. This confirms that the pond environment creates unique preservation conditions superior to room-temperature storage. The initial hypothesis, that the preservation effect was due to nitrogen gas formed within the pond ecosystem, was not fully supported, as direct nitrogen flushing did not reproduce the same results. This indicates that pond-based preservation is not solely attributable to nitrogen but is more likely the outcome of multiple ecological and physico-chemical factors, such as the presence of bound nitrogen compounds, carbon dioxide, or ammonia, which collectively contribute to a low-oxygen, spoilage-delaying environment. Overall, this work contributes in two key ways: first, by disproving the assumption that pond preservation is merely a variant of conventional MAP nitrogen systems; and second, by highlighting the role of pond-specific mechanisms that provide natural, eco-friendly preservation benefits. These findings establish pond-based storage as a promising, low-cost, and sustainable alternative preservation method, particularly relevant for tropical and resource-limited settings, while also opening pathways for further research into ecosystem-driven food preservation strategies.

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Authors' Contributions

Daimon Syukri was responsible for the conceptualization and methodology of the study and prepared the original draft of the manuscript. Rina Yenrina supervised the research activities and contributed to the review and editing of the manuscript. Rini: Research field collaborator, Syalki Habib Akbar, Fitria Indah Permata Sari, and Raja Darma Wulan conducted the experimental work and were responsible for data curation. Cesar Welya Refdi performed formal analysis and validation of the results. Efrina reviewed the revised manuscript. All authors have read and approved the final version of the manuscript.

Ethics

This study did not involve human participants or animal subjects. All experimental procedures were performed in accordance with institutional research guidelines and standard laboratory safety protocols.

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