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The Impact of Clean Label Products on Fruit Juice Safety and Quality

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ABSTRACT: The growing demand for foods with simple ingredient lists has increased interest in clean label preservation strategies across the fruit juice industry. Apple (Malus domestica) and peach (Prunus persica) juices are widely appreciated for their nutritional value and sensory properties; however, maintaining their safety and quality during processing and storage remains a major challenge. This study examines the scientific literature concerning the use of clean label preservation approaches in fruit juices, with particular attention to their influence on microbiological safety, physicochemical characteristics, nutritional value, sensory quality, and shelf-life. The available evidence indicates that organic acids, plant extracts, essential oils, natural antioxidants, and fermentation-derived antimicrobial compounds can contribute to microbial control while helping preserve key quality attributes. Their effectiveness, however, depends on factors such as fruit composition, processing conditions, storage environment, and the selected preservation strategy. The literature also shows that combining natural preservatives with non-thermal technologies, including high-pressure processing and pulsed electric fields, provides additional opportunities to improve product stability while reducing the use of synthetic additives. Although further research is required to optimize these preservation systems for commercial applications, clean label approaches represent a promising direction for producing fruit juices that meet current consumer expectations without compromising safety or quality.

KEYWORDS: clean label; fruit juice; apple juice; peach juice; natural preservatives; food safety.

1. INTRODUCTION

Fruit juices are widely consumed because they combine nutritional value with convenience, making them an important part of the daily diet in many countries. Among the different products available on the market, apple (*Malus domestica*) and peach (*Prunus persica*) juices remain popular due to their pleasant flavour, natural sweetness, and valuable content of vitamins, minerals, and antioxidant compounds (Jay et al., 2005). At the same time, consumer expectations have changed considerably. Besides good taste, there is increasing interest in products that contain fewer artificial ingredients and are perceived as more natural (Asioli et al., 2017; Choi et al., 2024).

Producing fruit juice that is both safe and of high quality is not a simple task. During processing and storage, undesirable changes may occur, including microbial spoilage, oxidation, colour deterioration, loss of nutrients, and changes in flavour. Although the naturally low pH of fruit juices limits the growth of many pathogenic microorganisms, yeasts, moulds, and acid-tolerant bacteria remain common causes of spoilage. For this reason, preservation has always been an essential step in fruit juice production (Jay et al., 2005; Davidson et al., 2013).

For decades, synthetic preservatives such as sodium benzoate and potassium sorbate have been widely used because they effectively control microbial growth and help extend product shelf life. However, consumers are increasingly paying attention to ingredient lists and often associate shorter, more familiar labels with healthier food choices. This shift has encouraged researchers and manufacturers to investigate preservation strategies that rely on naturally derived ingredients rather than synthetic additives (Asioli et al., 2017; Choi et al., 2024).

The concept of clean label has therefore become an important area of research within the fruit juice industry. Instead of depending solely on conventional preservatives, current studies are exploring the use of organic acids, plant extracts, essential oils, natural antioxidants, and antimicrobial compounds produced by beneficial microorganisms. These approaches aim to preserve microbiological safety while maintaining the physicochemical, nutritional, and sensory characteristics that determine product quality (Burt, 2004; Chauhan et al., 2024).

This study brings together recent findings on clean label preservation strategies used in fruit juices, with particular attention to apple and peach juices. It discusses the advantages and limitations of natural preservation systems, compares them with conventional approaches, and examines their influence on microbiological safety, physicochemical stability, nutritional quality, sensory properties, and shelf-life. The overall objective is to provide an updated overview of how clean label technologies may contribute to the production of safer and higher-quality fruit juice products.

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2. MATERIALS AND METHODS

The literature included in this study was collected from internationally recognized scientific databases, including Scopus, Web of Science, PubMed, and Google Scholar. The search focused on studies related to clean label preservation strategies in fruit juices, particularly those involving apple (*Malus domestica*) and peach (*Prunus persica*) juices.

Keywords used during the literature search included *clean label*, *fruit juice*, *apple juice*, *peach juice*, *natural preservatives*, *food safety*, *microbiological quality*, *physicochemical properties*, *shelf-life*, and *non-thermal processing*. Preference was given to peer-reviewed articles published in recent years, while earlier publications were included when they represented fundamental contributions to fruit juice preservation or food microbiology (Jay et al., 2005).

The selected publications were examined to identify information concerning conventional preservatives, natural preservation systems, microbiological safety, physicochemical and nutritional quality, sensory characteristics, and shelf-life stability. Only studies directly related to fruit juices and relevant to the objectives of this study were considered.

3. RESULTS AND DISCUSSION

3.1 Clean Label Preservation in Fruit Juices

The concept of clean label preservation has gained increasing importance in the fruit juice industry, especially in products such as apple (*Malus domestica*) and peach (*Prunus persica*) juices, where safety, natural composition, and sensory quality are key factors for consumer acceptance. Although the term "clean label" does not have a single official definition, it is generally linked with the reduction of synthetic additives and the use of ingredients that are natural, familiar, and easily understood by consumers (Asioli et al., 2017; Choi et al., 2024).

The reviewed literature shows that clean label preservation is not limited to replacing one synthetic preservative with one natural ingredient. Instead, it represents a broader technological approach that aims to maintain microbiological stability, physicochemical quality, nutritional value, and shelf-life with fewer artificial additives. This is particularly relevant for fruit juices, which are naturally acidic but still vulnerable to spoilage caused by yeasts, moulds, and acid-tolerant microorganisms (Jay et al., 2005).

Organic acids, plant extracts, essential oils, natural antioxidants, and fermentation-derived antimicrobial compounds have been reported as the most commonly investigated clean label alternatives in fruit juice preservation. Their effectiveness, however, depends strongly on the type of juice, pH, storage temperature, concentration, and interaction with other juice components. For this reason, results obtained in one fruit juice matrix cannot always be directly applied to another (Burt, 2004; Chauhan et al., 2024).

In apple and peach juices, clean label strategies are especially relevant because preservation must be achieved without negatively affecting taste, aroma, colour, and nutritional quality. The main challenge is therefore not only microbial control, but the balance between safety, product stability, and consumer acceptance. Based on the reviewed studies, combined preservation approaches appear more promising than the use of a single natural ingredient alone.

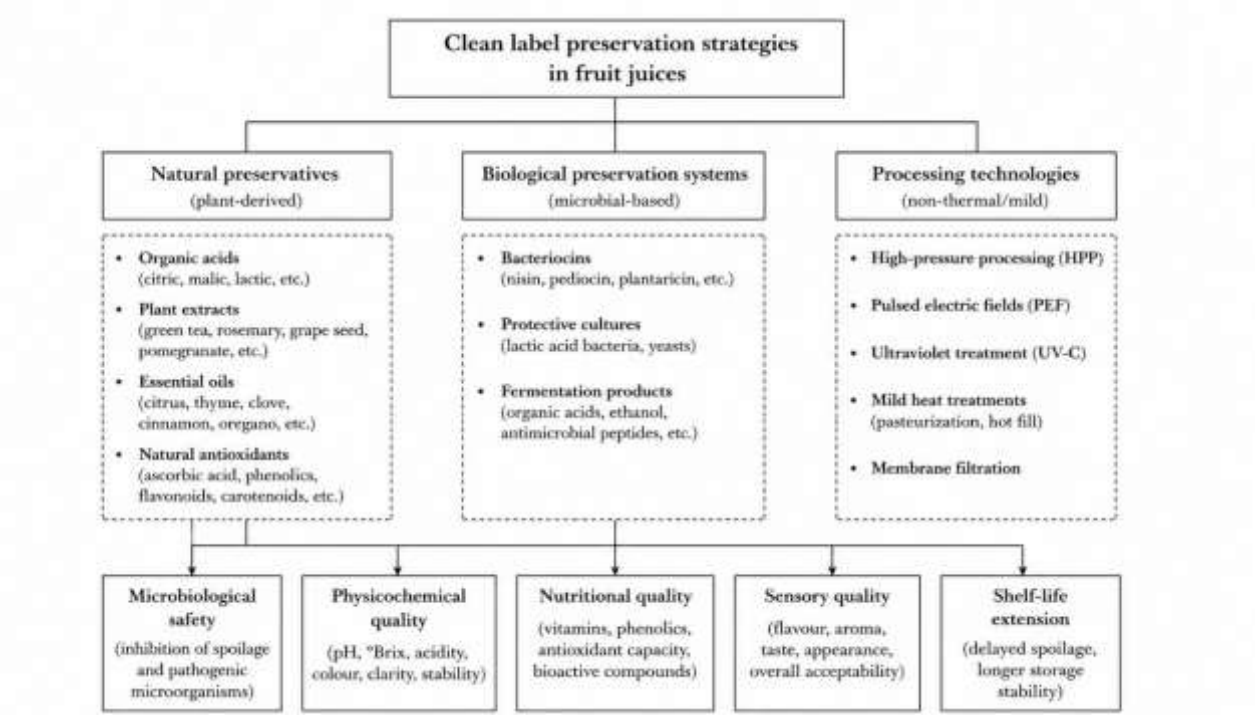


Figure 1. Classification of Clean Label Preservation Strategies Applied in Fruit Juices

3.2 Conventional and Clean Label Preservation Strategies

For many years, synthetic preservatives have been the standard approach for maintaining the microbiological stability of fruit juices. Compounds such as sodium benzoate, potassium sorbate, sulfites, and dimethyl dicarbonate have been widely used because of their proven ability to inhibit spoilage microorganisms and prolong shelf life. Their effectiveness has been well documented, particularly in acidic beverages where microbial growth can be controlled with relatively low concentrations (Davidson et al., 2013).

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Despite these advantages, consumer preferences have gradually shifted toward products with simpler ingredient lists and fewer synthetic additives. This change has encouraged the food industry to explore preservation strategies based on naturally derived compounds rather than replacing one preservative with another. As a result, clean label preservation has become an important area of research in fruit juice production (Asioli et al., 2017; Choi et al., 2024).

Organic acids, plant extracts, essential oils, natural antioxidants, and antimicrobial compounds produced by beneficial microorganisms have received considerable attention as potential alternatives. These ingredients may contribute to microbial control while helping preserve the physicochemical and sensory properties of fruit juices. However, their performance is influenced by several factors, including fruit variety, pH, processing conditions, storage temperature, and interactions within the juice matrix (Burt, 2004; Chauhan et al., 2024).

Rather than viewing conventional and clean label preservatives as competing approaches, recent studies increasingly support their complementary role. Combining natural antimicrobial compounds with modern preservation technologies, including high-pressure processing and pulsed electric fields, has produced encouraging results in maintaining both safety and product quality. This integrated strategy appears particularly suitable for apple and peach juices, where preserving the natural flavour and nutritional characteristics is as important as controlling microbial growth (Rawson et al., 2011; Lisboa et al., 2024).

3.3 Effect of Clean Label Preservation on Microbiological Safety

Microbiological stability remains one of the main challenges in fruit juice production, particularly in products intended for extended storage. Although the acidic nature of apple and peach juices limits the growth of many pathogenic bacteria, spoilage caused by yeasts, moulds, and acid-tolerant microorganisms continues to affect product quality and shelf-life. For this reason, preservation strategies are expected not only to delay microbial growth but also to maintain the natural characteristics of the juice (Jay et al., 2005; Davidson et al., 2013).

Published studies indicate that several clean label ingredients are capable of reducing microbial populations through different mechanisms. Organic acids primarily act by lowering intracellular pH, creating conditions that are less favourable for microbial survival. Plant extracts rich in phenolic compounds have also demonstrated antimicrobial activity, although their effectiveness varies depending on the botanical source, extraction method, and concentration applied. Essential oils have shown broad-spectrum activity against spoilage microorganisms; however, their practical use is often limited by their strong aroma and flavour, particularly when higher concentrations are required (Burt, 2004; Chauhan et al., 2024).

Another group of compounds receiving increasing attention includes bacteriocins and other antimicrobial metabolites produced by beneficial microorganisms. Unlike many plant-derived compounds, these substances exhibit selective antimicrobial activity and can be incorporated into preservation systems without substantially altering the sensory profile of fruit juices. Their application has been investigated both individually and in combination with other preservation methods (Cleveland et al., 2001; Settanni & Corsetti, 2008).

Recent studies also suggest that the most consistent results are obtained when natural preservatives are combined with non-thermal processing technologies, such as high-pressure processing or pulsed electric fields. These approaches reduce the microbial load while minimizing the thermal damage commonly associated with conventional pasteurization. As a result, they offer an opportunity to improve microbiological safety without compromising the nutritional and sensory quality of fruit juices (Rawson et al., 2011; Lisboa et al., 2024).

Taken together, the available evidence indicates that clean label preservation can provide an effective level of microbial control when the preservation strategy is selected according to the characteristics of the juice. Rather than replacing conventional preservatives with a single natural ingredient, current research increasingly supports the use of integrated preservation systems that combine natural antimicrobial compounds with modern processing technologies.

Table 1. Main Clean Label Preservation Strategies Applied in Fruit Juices

Strategy	Main effect	Reported benefit
Organic acids	pH reduction	Inhibits microbial growth
Plant extracts	Phenolic compounds	Antimicrobial and antioxidant activity
Essential oils	Membrane disruption	Reduces bacteria, yeasts and moulds
Bacteriocins	Selective antimicrobial activity	Controls spoilage microorganisms
Natural preservatives + HPP/PEF	Combined preservation	Improves microbial stability and shelf-life

Table 1. *Summary of the main clean label preservation strategies reported for improving the microbiological safety of fruit juices.*

3.4 Effect of Clean Label Preservation on Physicochemical and Nutritional Quality

The quality of fruit juices is closely linked to their physicochemical and nutritional characteristics. Parameters such as pH, soluble solids (°Brix), titratable acidity, colour, and vitamin C content are commonly used to evaluate product stability during processing and storage. In apple and peach juices, preserving these attributes is particularly important because they directly influence both product quality and consumer acceptance (Jay et al., 2005).

Unlike conventional preservatives, clean label ingredients are expected to protect juice quality without substantially changing its natural composition. Organic acids are widely used because they help maintain the acidic conditions required for microbial stability while having only a limited effect on the original characteristics of the juice. Plant extracts and naturally occurring antioxidants have also attracted considerable attention due to their ability to reduce oxidative reactions that contribute to colour changes and nutrient degradation during storage (Choi et al., 2024; Lisboa et al., 2024).

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Among the nutritional components, vitamin C is considered one of the most sensitive to processing and storage conditions. Several studies have shown that preservation strategies based on natural antioxidants and non-thermal technologies can improve vitamin C retention compared with conventional thermal treatments. Similar observations have been reported for phenolic compounds, which contribute not only to the antioxidant capacity of fruit juices but also to their overall nutritional value (Rawson et al., 2011; Lisboa et al., 2024).

It should be noted, however, that the effectiveness of clean label preservation is not identical for every fruit juice. Differences in fruit composition, processing conditions, and storage environment may influence the response of individual quality parameters. Consequently, selecting an appropriate preservation strategy requires consideration of the specific characteristics of each juice rather than relying on a single universal approach.

Overall, the available literature suggests that clean label preservation can maintain the physicochemical and nutritional quality of fruit juices while supporting the growing demand for products with simpler ingredient lists. Continued research is expected to improve these preservation systems and facilitate their wider application in commercial juice production.

3.5 Effect of Clean Label Preservation on Sensory Quality and Shelf-Life

The success of any preservation strategy depends not only on its ability to control microbial growth but also on its influence on the sensory characteristics of the final product. Colour, aroma, taste, and overall acceptability are among the main factors that determine consumer preference for fruit juices. Even when microbiological safety is achieved, noticeable changes in these attributes may reduce product acceptance (Asioli et al., 2017; Choi et al., 2024).

One of the advantages of clean label preservation is its potential to maintain the natural sensory profile of fruit juices. Organic acids generally have little influence on flavour when applied at appropriate concentrations, whereas plant extracts and natural antioxidants may help preserve colour and reduce oxidative changes during storage. Essential oils have demonstrated strong antimicrobial activity, but their application requires careful formulation because excessive concentrations can modify the characteristic aroma and taste of the juice (Burt, 2004; Choi et al., 2024).

Shelf-life is closely related to both microbiological stability and the preservation of quality attributes over time. Recent studies indicate that combining natural preservatives with non-thermal processing technologies can delay quality deterioration while maintaining the fresh characteristics of fruit juices. This approach has shown particular promise for products where extended storage is required without increasing the use of synthetic additives (Rawson et al., 2011; Lisboa et al., 2024).

Although the reported findings are encouraging, shelf-life is influenced by several factors beyond the preservation system itself. Fruit composition, packaging materials, storage temperature, and processing conditions all contribute to the stability of the final product. Consequently, preservation strategies should be selected according to the characteristics of each juice rather than applying a single solution to all products.

Overall, clean label preservation offers an opportunity to improve product stability while preserving the sensory qualities expected by consumers. Continued technological development is likely to support wider industrial application, particularly in apple and peach juices where maintaining a fresh flavour and natural appearance is essential.

Table 2. Reported Effects of Clean Label Preservation on Fruit Juice Quality

Quality parameter	Effect of clean label preservation	Reported outcome
Colour	Reduces oxidative changes	Better colour stability
Vitamin C	Slows oxidative degradation	Higher vitamin C retention
Phenolic compounds	Preserves natural antioxidants	Improved antioxidant capacity
Sensory quality	Maintains flavour and aroma	Higher consumer acceptance
Shelf-life	Delays quality deterioration	Extended storage stability

Table 2. *Summary of the reported effects of clean label preservation strategies on the quality and shelf-life of fruit juices.*

CONCLUSION

The findings discussed in this study demonstrate that clean label preservation has become an important direction in the development of safer and higher-quality fruit juices. Natural preservation strategies, including organic acids, plant extracts, essential oils, natural antioxidants, and fermentation-derived antimicrobial compounds, offer promising alternatives to conventional synthetic preservatives. When properly selected and applied, these approaches can contribute to improved microbiological safety while maintaining the physicochemical, nutritional, and sensory characteristics of fruit juices.

The available literature also indicates that the best results are often achieved by combining natural preservatives with modern non-thermal processing technologies. Such integrated approaches make it possible to reduce the use of synthetic additives without compromising product stability or consumer acceptance. However, the effectiveness of clean label preservation depends on several factors, including fruit composition, processing conditions, storage environment, and the characteristics of the preservation system itself.

Although considerable progress has been made, further work is still required to standardize natural preservation strategies and evaluate their performance under commercial production conditions. Continued research in this area will support the development of fruit juices that satisfy both industrial requirements and the growing consumer demand for products with simple ingredient lists, high quality, and improved safety.

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