



A review: Enzymes used in honey coffee production

Nhi Y Dinh, Phu H Le

Department of Food Technology, School of Biotechnology, International University, Ho Chi Minh City, Vietnam, Vietnam

National University, Ho Chi Minh City, Vietnam

Corresponding Author: Phu H Le

Abstract

Honey processing combines wet and dry processing, removing the pulp but keeping mucilage before drying. Thus, impurities from pulp could be avoided and potentially allow the well-controlled fermentation of the mucilage around the coffee seeds. Enzymes play a central role in this process by driving key biochemical transformations that regulate mucilage degradation, fermentation dynamics, and flavor precursor formation. This paper reviews the composition of coffee mucilage, the major types and sources of enzymes involved in honey coffee production, and the mechanisms through which these enzymes act during fermentation and drying. Particular emphasis is placed on pectinases, cellulases, proteases, glycosidases, and oxidative enzymes, which collectively influence sugar metabolism, mass transfer, microbial activity, and phenolic transformations. The intentional application of commercial enzymes is also discussed as a strategy to improve process control, reduce drying time, and enhance consistency in sensory quality. Evidence from the literature indicates that enzyme-assisted honey coffee processing can improve sweetness, fruity and caramel-like notes, and flavor uniformity while reducing defects associated with uneven fermentation and prolonged drying. However, challenges related to enzyme optimization, cost, sustainability, and producer adoption remain. Overall, understanding enzymatic roles in honey coffee processing provides a scientific foundation for improving processing efficiency, sensory quality, and reproducibility in specialty coffee production.

Keywords: Honey coffee processing, enzymes, mucilage degradation, fermentation, coffee quality

Introduction

Coffee is among the most economically significant agricultural commodities worldwide, and its sensory quality is profoundly influenced by postharvest processing practices that regulate biochemical and microbiological transformations within the coffee cherry. Postharvest processing determines the extent of mucilage removal, fermentation dynamics, and precursor formation, all of which ultimately affect the chemical composition and sensory attributes of roasted coffee (Girma & Sualeh, 2022; Cao *et al.*, 2023) ^[4, 12]. In recent years, honey coffee processing, also referred to as pulped natural processing, has emerged as an increasingly important method within the specialty coffee sector due to its capacity to enhance sweetness, mouthfeel, and aromatic complexity while reducing water consumption compared with conventional wet processing (Shehasen, 2024) ^[17].

Honey coffee processing is characterized by the partial removal of the coffee cherry skin while retaining a controlled proportion of mucilage on the parchment during drying. This mucilage layer is rich in pectic substances, sucrose, cellulose, hemicellulose, and minor proteins, creating a substrate conducive to intense enzymatic activity. Unlike fully washed processing, where mucilage is largely removed through extensive fermentation and washing, honey processing relies on the gradual enzymatic degradation of mucilage during drying and limited fermentation, making enzyme-mediated reactions a critical determinant of processing efficiency and coffee quality.

Enzymes play an important role in the hydrolysis of complex macromolecules present in coffee mucilage. Pectinases, cellulases, hemicellulases, amylases, proteases, and invertases catalyze the breakdown of polysaccharides and proteins into fermentable sugars, amino acids, and other

low-molecular-weight compounds (Basheer *et al.*, 2022; Motta *et al.*, 2023) ^[2, 14]. These enzymatic reactions regulate mucilage viscosity, drying kinetics, and metabolite availability, thereby influencing microbial succession and fermentation pathways. In the context of honey coffee production, where mucilage is intentionally retained, the regulation of enzymatic activity is particularly important to prevent undesirable fermentation while promoting favorable flavor development.

Microorganisms naturally associated with coffee cherries constitute the primary source of enzymatic activity during honey coffee processing. Yeasts, lactic acid bacteria, and acetic acid bacteria secrete extracellular enzymes that contribute to mucilage degradation and the formation of organic acids, alcohols, esters, and other volatile compounds (Haile & Kang, 2019; Shen *et al.*, 2024) ^[13, 16]. Recent research has demonstrated that modifications in fermentation conditions, including oxygen availability and moisture content, can significantly influence microbial diversity and enzymatic expression, leading to measurable improvements in coffee quality (Braga *et al.*, 2023) ^[3]. These findings highlight the complex interactions between microbial ecology and enzymatic function in semi-dry processing systems.

Moreover, enzymatic transformations occurring during honey coffee processing strongly affect the pool of aroma and flavor precursors available for subsequent roasting. The enzymatic release of reducing sugars and free amino acids enhances Maillard and Strecker reactions during roasting, thereby contributing to the formation of desirable aroma compounds such as aldehydes, pyrazines, and furans (Cao *et al.*, 2023) ^[4]. Consequently, enzymatic activity during honey processing exerts both direct and indirect effects on the sensory profile of the final beverage.

Despite growing interest in honey coffee processing, a comprehensive synthesis focusing specifically on the types of enzymes involved, their sources, mechanisms of action, and impact on coffee quality remains limited. This review aims to address this gap by summarizing current knowledge on enzymes used in honey coffee production, emphasizing their biochemical roles, contributions to sensory and functional properties of coffee. A better understanding of enzymatic processes in honey coffee production can support the development of more controlled, sustainable, and high-quality coffee processing practices.

Composition of coffee mucilage

1. Chemical structure of coffee mucilage

Coffee mucilage is a viscous layer located between the pulp and parchment of the coffee cherry and plays a critical role in postharvest processing, particularly in honey coffee production. Its chemical composition largely determines fermentation behavior, drying kinetics, and the development of sensory attributes in the final product.

Pectin is the principal structural component of coffee mucilage, accounting for approximately 1–3% of the fresh coffee cherry mass (De Melo Pereira *et al.*, 2019)^[8]. Chemically, pectin is a complex heteropolysaccharide composed primarily of a linear backbone of α -1,4-linked D-galacturonic acid units (homogalacturonan), interspersed with rhamnose residues that form branching regions. These branches are substituted with neutral sugars such as arabinose and galactose, creating a highly hydrated and gel-like structure. In plant tissues, pectin is closely associated with structural proteins in the primary cell wall, contributing to cell adhesion, water retention, and tissue integrity (Voragen *et al.*, 2009)^[19]. In coffee, pectin-rich mucilage serves as a major substrate for microbial metabolism during fermentation.

In addition to pectin, coffee mucilage and surrounding tissues contain cellulose and hemicellulose, which form the rigid framework of plant cell walls. Cellulose consists of linear chains of β -1,4-linked glucose units, while hemicellulose comprises a heterogeneous group of branched polysaccharides, including xylans and mannans. Although these polymers are less readily fermentable than pectin, their partial enzymatic degradation increases cell wall permeability and facilitates the diffusion of soluble compounds during processing (Farah, 2012)^[10].

Coffee mucilage is a carbohydrate-rich matrix that contains readily soluble sugars, primarily sucrose together with glucose and fructose, which serve as important substrates for microbial metabolism during fermentation. These fermentable sugars support the growth and activity of yeasts and bacteria, leading to biochemical transformations that influence the chemical composition of the mucilage and ultimately affect coffee quality (Elhalis *et al.*, 2023^[9]; Silva *et al.*, 2013). In addition, mucilage contains minor amounts of phenolic compounds that contribute to antioxidant properties and may influence sensory attributes such as bitterness or astringency when fermentation or drying processes are not properly controlled (Fontana & Durand, 2017; da Silva *et al.*, 2014)^[5, 11].

2. Importance of mucilage degradation in Honey coffee processing

In honey coffee processing, mucilage is intentionally retained on the parchment during drying, distinguishing this

method from washed coffee processing. As a result, controlled mucilage degradation is essential to ensure uniform drying, regulate microbial activity, and promote desirable biochemical transformations. During fermentation, pectin degradation occurs primarily through the action of microbial pectinases, particularly polygalacturonase and pectin lyase, which cleave the pectin backbone and reduce mucilage viscosity (De Melo Pereira *et al.*, 2019)^[8].

The activity of these enzymes is a key factor in coffee fermentation and is often used as a selection criterion for microbial starter cultures in controlled fermentation. Effective mucilage degradation allows sugars and metabolites to remain in close contact with the coffee bean without forming excessively thick or sticky layers, thereby supporting balanced sweetness, acidity, and aroma development while minimizing fermentation defects (Haile & Kang, 2019)^[13].

Although honey or pulped-natural coffee processing is associated with the development of complex sweetness and distinctive sensory characteristics, the process also presents several operational challenges. Fermentation in coffee processing generally occurs spontaneously and is driven by indigenous microbial communities naturally present on the coffee cherries and surrounding environment, resulting in considerable variability in microbial composition and metabolic activity (Aswathi *et al.*, 2023^[1]; Shen *et al.*, 2025). Such variability can influence mucilage degradation and metabolite formation during fermentation, potentially leading to inconsistent processing outcomes and variations in coffee quality. Furthermore, inadequate control of fermentation and drying conditions may promote undesirable microbial activity and the formation of metabolites associated with off-flavors, including sour or alcoholic notes (Aswathi *et al.*, 2023^[1]; Shen *et al.*, 2025).

The application of enzymes, particularly pectinases and cellulases, provides a targeted approach to overcoming these limitations. Enzymes accelerate mucilage degradation by selectively hydrolyzing pectin and cell wall polysaccharides under mild conditions, reducing viscosity and facilitating uniform drying. Enzyme-assisted processing allows for greater control over fermentation dynamics without the need for extensive washing, thereby preserving the characteristic sweetness, body, and mouthfeel associated with honey-processed coffees (Haile & Kang, 2019)^[13].

Removing or modifying mucilage without washing presents a significant technological challenge due to limited water availability and the impracticality of mechanical removal. Under these semi-dry conditions, enzymatic treatment is particularly suitable because enzymes can function effectively at relatively low water activity and exhibit high substrate specificity. Pectinases and cellulases selectively degrade mucilage components without damaging the coffee bean structure or excessively leaching soluble compounds. Consequently, enzymatic approaches offer a scientifically sound solution for managing mucilage in honey coffee processing, enabling improved processing efficiency, reduced drying time, and enhanced consistency in sensory quality while maintaining the distinctive characteristics of honey-processed coffee (De Melo Pereira *et al.*, 2019)^[8].

Types of enzymes used in Honey Coffee production

Honey coffee production is characterized by the partial removal of the coffee cherry skin while retaining varying amounts of mucilage on the parchment during drying. This

mucilage-rich environment creates favorable conditions for enzymatic reactions that strongly influence sugar metabolism, fermentation dynamics, and flavor precursor development. The enzymes involved in honey coffee processing originate from three main sources: the coffee fruit itself, associated microorganisms, and, in some cases, externally added commercial enzymes. The major enzyme groups involved are described below.

1. Pectinases (Pectinolytic Enzymes)

Pectinases are among the most critical enzymes involved in honey coffee production due to the high pectin content of coffee mucilage. This group of enzymes, which includes polygalacturonase, pectin lyase, and pectin methylesterase, catalyzes the depolymerization of pectic substances into smaller, water-soluble molecules. Through the cleavage of the pectin backbone and the removal of methyl ester groups, pectinases progressively weaken the gel-like structure of the mucilage. In honey coffee processing, precise control of pectinolytic activity is essential because the mucilage is intentionally retained rather than fully removed, as in washed coffee. Partial pectin degradation lowers mucilage viscosity, allowing for more even drying and improved oxygen diffusion while preventing the accumulation of excessively thick mucilage layers that could promote uncontrolled microbial growth. This enzymatic activity originates from both endogenous pectinases naturally present in the coffee fruit and microbial pectinases produced by yeasts and bacteria during fermentation. Balanced pectinolysis plays a key role in regulating fermentation intensity and duration, thereby influencing the chemical environment surrounding the coffee bean. Adequate pectin breakdown supports the gradual release and retention of sugars, contributing to desirable sweetness and acidity, while excessive pectinolytic activity may lead to over-fermentation and sensory defects. Therefore, controlled pectinase action is a determining factor in achieving consistent quality and favorable sensory attributes in honey-processed coffees (De Melo Pereira *et al.*, 2019; Haile & Kang, 2019)^[8, 13].

2. Cellulase

Cellulase plays a significant role in honey coffee production by catalyzing the hydrolysis of cellulose, a major structural polysaccharide present in the cell walls of the coffee fruit, mucilage, and parchment layers. Although cellulose itself is not a primary source of fermentable sugars for microorganisms, its enzymatic degradation increases cell wall permeability and weakens the structural matrix surrounding the coffee bean. This action facilitates the release and diffusion of soluble compounds, including sugars, organic acids, and other metabolites, into the surrounding mucilage. During honey coffee processing, where a substantial portion of mucilage is intentionally retained on the parchment, cellulase activity supports the partial disintegration of plant tissues under semi-dry fermentation conditions. By breaking down β -1,4-glycosidic bonds in cellulose, cellulase enhances mass transfer between the mucilage, microorganisms, and the bean surface. This improved mass transfer promotes more uniform fermentation and allows other enzymes, such as invertases and pectinases, to access their substrates more effectively. Furthermore, cellulase indirectly contributes to flavor development by modulating the kinetics of fermentation and

drying. The gradual loosening of cell wall structures slows excessive sugar loss while maintaining prolonged contact between sugars and the coffee bean during drying. This extended interaction favors the accumulation of flavor precursors and supports the formation of desirable fermentation metabolites, such as organic acids and esters, which enhance sweetness, body, and aromatic complexity in the final cup. Consequently, controlled cellulase activity is considered an important factor in achieving balanced and high-quality sensory attributes in honey-processed coffees (Silva *et al.*, 2019)^[13].

3. Proteases and Peptidases

Proteases hydrolyze proteins into peptides and free amino acids, which are crucial flavor precursors. During honey coffee processing, proteolytic activity occurs at a moderate level due to limited water availability compared with wet fermentation.

The amino acids released by proteases play a key role during roasting, participating in Maillard reactions that generate aroma compounds such as pyrazines, aldehydes, and furans. Microbial proteases, particularly from yeasts and lactic acid bacteria, are considered more influential than endogenous coffee proteases during postharvest processing (Farah, 2012; De Bruyn *et al.*, 2017)^[7, 10].

4. Glycosidases (β -Glucosidase)

β -Glucosidase (EC 3.2.1.21) is a key glycosidase involved in flavor development during honey coffee processing because it hydrolyzes β -glycosidic bonds, releasing glucose and aroma-active aglycones from non-volatile glycosylated precursors. In coffee and other plant-based foods, many important aroma compounds exist in bound forms and require enzymatic cleavage to become volatile and sensorially active. Microbial β -glucosidases are therefore recognized for their ability to unlock hidden flavor potential during fermentation by liberating terpenes, phenolic derivatives, and related aromatic compounds (Muradova *et al.*, 2023)^[15]. Evidence from coffee fermentation studies shows that enzymatic systems associated with fungi can significantly modify both volatile and non-volatile profiles; for example, Tang *et al.* (2021)^[18] demonstrated that solid-state fungal fermentation of *Coffea canephora* altered volatile composition and enhanced desirable aroma compounds, suggesting the contribution of β -glucosidase activity in transforming glycosidically bound precursors. In honey coffee processing, where mucilage remains partially attached to the bean under semi-dry conditions, β -glucosidase produced by yeasts and fungi may enhance fruity and floral notes through gradual deglycosylation, although careful control of fermentation parameters is necessary to maintain balanced sensory quality and avoid flavor deviations.

5. Oxidative enzymes (Polyphenol Oxidase and Peroxidase)

Oxidative enzymes such as polyphenol oxidase (PPO) and peroxidase catalyze the oxidation of phenolic compounds. In honey coffee, where mucilage remains and drying is relatively slow, these enzymes can influence bean color and phenolic composition.

Moderate oxidative activity may contribute to flavor complexity, while excessive activity can lead to browning reactions and off flavors. Therefore, controlling

temperature, oxygen exposure, and drying rate is essential to regulate the effects of these enzymes during honey processing (Farah, 2012) ^[10].

6. Commercially added enzymes

In recent years, commercial enzyme preparations primarily pectinases and cellulases have been applied experimentally in honey coffee production to improve process consistency. These enzymes allow producers to control mucilage breakdown, reduce drying time, and standardize flavor outcomes. Compared with spontaneous enzymatic activity, commercial enzymes offer greater predictability but require careful optimization to avoid excessive degradation of desirable compounds (Haile & Kang, 2019) ^[13].

Mechanisms of enzyme action during Honey coffee fermentation and drying

Honey coffee fermentation and drying represent a unique biochemical environment in which enzymatic reactions occur under semi-dry conditions, characterized by limited free water, high sugar concentration, and gradual moisture reduction. Unlike fully washed coffee, honey processing retains part or all the mucilage on the parchment, allowing enzymes to act continuously during both fermentation and drying stages. The mechanisms of enzyme action in this process are closely linked to substrate availability, microbial activity, temperature, oxygen exposure, and water activity.

1. Enzymatic degradation of mucilage during fermentation

Coffee mucilage is primarily composed of pectins, sucrose, reducing sugars, and minor amounts of proteins and minerals. During honey coffee fermentation, pectinolytic enzymes initiate the breakdown of the pectin-rich mucilage matrix. Endogenous pectinases from the coffee fruit and microbial pectinases secreted by yeasts and bacteria hydrolyze α -1,4-glycosidic bonds in polygalacturonic acid, reducing mucilage viscosity. This partial degradation is a defining feature of honey processing: mucilage is softened rather than completely removed. As a result, sugars remain in close contact with the bean surface for extended periods. The gradual enzymatic breakdown regulates fermentation speed, limits excessive microbial proliferation, and supports controlled metabolite production. The extent of pectin hydrolysis directly influences drying behavior and the risk of over-fermentation (De Melo Pereira *et al.*, 2019) ^[8].

2. Sugar metabolism and carbohydrase activity

Invertases and other carbohydrases play a central role in sugar metabolism during honey coffee processing. Invertase catalyzes the hydrolysis of sucrose into glucose and fructose, increasing the pool of fermentable sugars available to microorganisms. These monosaccharides are rapidly assimilated by yeasts and lactic acid bacteria, leading to the production of organic acids, alcohols, and aroma-active esters. Because honey processing involves slower moisture loss than natural processing but less water than washed fermentation, enzyme activity occurs under progressively decreasing water activity. This condition favors sustained but moderate enzymatic reactions, preventing abrupt sugar depletion. The gradual conversion of sugars contributes to perceived sweetness, balanced acidity, and complexity in the final cup (Silva *et al.*, 2019) ^[13].

3. Proteolysis and formation of flavor precursors

Proteolytic enzymes act on coffee proteins during fermentation and early drying stages. Microbial proteases and peptidases hydrolyze proteins into peptides and free amino acids, which accumulate as non-volatile flavor precursors. Although proteolysis is less intense in honey coffee than in wet fermentation due to lower water availability, the prolonged contact time between mucilage, microorganisms, and bean surface allows meaningful precursor formation. These amino acids play a crucial role during roasting, where they participate in Maillard and Strecker reactions, generating key aroma compounds such as aldehydes, ketones, and heterocyclic compounds. Thus, enzymatic proteolysis during honey processing indirectly determines roasted coffee aroma and flavor intensity (Farah, 2012; De Bruyn *et al.*, 2017) ^[7,10].

4. Enzymatic release of bound aroma compounds

Some aroma compounds in coffee are present as glycosidically bound, non-volatile precursors that release odor-active aglycones during roasting (De Rosso *et al.*, 2022) ^[6]. β -glucosidase produced by microorganisms catalyze the hydrolysis of glycosidic aroma precursors, leading to the liberation of volatile aglycones and changes in the pool of flavor precursors during processing (Muradova *et al.*, 2023) ^[15]. In honey coffee, the semi-dry environment and extended processing time favor gradual deglycosylation without rapid volatilization losses. This mechanism enhances the potential for floral, fruity, and sweet notes to develop during roasting. While most aroma release occurs thermally, enzymatic action during processing determines the availability and diversity of aroma precursors (De Rosso *et al.*, 2022) ^[6].

5. Oxidative enzyme activity during drying

As fermentation transitions into drying, oxidative enzymes such as polyphenol oxidase (PPO) and peroxidase become increasingly influential. These enzymes catalyze the oxidation of phenolic compounds in the presence of oxygen, leading to the formation of quinones and subsequent polymerization reactions. In honey coffee, slow drying and mucilage retention increase exposure time to oxygen, enhancing oxidative reactions. Controlled oxidative activity can contribute to flavor complexity and color development, whereas excessive activity may result in undesirable browning and bitterness. Producers manage these effects by controlling drying temperature, layer thickness, and airflow, thereby indirectly regulating enzyme activity (Farah, 2012) ^[10].

6. Interaction between enzymatic activity and drying kinetics

Drying progressively reduces water activity, which in turn limits enzyme mobility and reaction rates. In honey coffee processing, enzyme action does not cease abruptly but gradually declines as moisture content decreases. This extended enzymatic window allows slow, continuous biochemical transformations that differentiate honey coffee from washed and natural coffees. The balance between fermentation and drying is therefore critical: rapid drying may prematurely halt enzymatic reactions, while excessively slow drying may prolong enzyme activity beyond optimal levels, increasing the risk of defects. Understanding this interaction enables better control of

enzymatic mechanisms and supports consistent quality outcomes in honey coffee production (Haile & Kang, 2019)^[13].

Impact of enzyme use on coffee quality

The use of enzymes in honey coffee processing significantly influences both the physical–chemical properties of coffee during processing and the sensory quality of the final product. Enzymatic treatments, particularly those involving pectinases and cellulases, accelerate mucilage degradation by hydrolyzing pectin and cell wall polysaccharides, resulting in faster and more uniform mucilage removal under semi-dry conditions. This reduction in mucilage viscosity improves drying efficiency and shortens drying time, thereby decreasing the window for uncontrolled microbial growth and reducing the risk of microbial contamination. Moreover, enzymatic degradation of structural polysaccharides enhances mass transfer and sugar diffusion within the mucilage layer, allowing fermentable sugars to remain in close contact with the coffee bean during fermentation and early drying stages (De Melo Pereira *et al.*, 2019; Haile & Kang, 2019)^[8, 13].

These physical and chemical changes translate into notable improvements in sensory quality. Enzyme-assisted honey coffee processing is commonly associated with increased sweetness and enhanced fruity flavor notes, which result from greater availability of fermentable sugars and more controlled fermentation dynamics. At the same time, enzymatic treatments can reduce undesirable grassy, vegetal, or astringent characteristics that often arise from incomplete mucilage degradation or uneven fermentation. Improved uniformity of mucilage breakdown across beans also contributes to more consistent flavor profiles within a batch. In addition, the controlled release and retention of sugars and amino acid precursors during processing can enhance chocolate, caramel, and honey-like notes after roasting, which are highly valued attributes in specialty honey-processed coffees (Farah, 2012; De Bruyn *et al.*, 2017)^[7, 10].

Cupping evaluations further demonstrates the positive impact of enzyme application on coffee quality. Studies generally report upward trends in cupping scores for enzyme-treated honey coffees compared with untreated controls, particularly in attributes such as sweetness, balance, and overall flavor clarity. Optimal enzyme concentrations are critical to achieving these benefits; moderate levels, often reported around 2% (w/w) depending on enzyme activity and formulation, tend to produce the most favorable sensory outcomes. At these concentrations, enzymatic activity enhances mucilage degradation without excessively accelerating fermentation. In contrast, excessive enzyme application may lead to over-fermentation, excessive acid production, and the development of off-flavors, ultimately resulting in reduced cupping scores (De Melo Pereira *et al.*, 2019; Haile & Kang, 2019)^[8, 13].

Despite the demonstrated benefits, several challenges and considerations must be addressed when implementing enzyme-assisted honey coffee processing. The cost and limited accessibility of commercial enzyme preparations may restrict adoption, particularly among smallholder farmers. In addition, inadequate control of enzyme dosage, fermentation time, or environmental conditions can increase the risk of over-fermentation and undesirable sensory outcomes. Precise process control and technical knowledge

are therefore essential to ensure consistent quality. Environmental and sustainability considerations also arise, as producers must evaluate the ecological footprint of enzyme production and application. Furthermore, farmer acceptance and appropriate training are critical to ensure correct enzyme use and to maximize the potential benefits of this technology (Haile & Kang, 2019)^[13].

Future perspectives for enzyme use in honey coffee processing are promising. The development of tailored enzyme cocktails specifically designed for honey processing could enable more targeted degradation of pectin and cellulose while preserving desirable compounds. The use of indigenous microorganisms capable of producing enzymes on-farm represents a sustainable alternative to commercial enzymes and may enhance terroir-specific flavor characteristics. Integration of enzymatic treatments with controlled fermentation using selected starter cultures offers further opportunities to improve consistency and reproducibility in coffee quality. Finally, advances in biotechnology aimed at modulating aroma precursor formation and enhancing flavor complexity hold significant potential for the future development of high-quality, differentiated honey-processed coffees (De Bruyn *et al.*, 2017; De Melo Pereira *et al.*, 2019)^[7, 8].

Conclusion

Enzymes play a central role in honey coffee production by governing mucilage degradation, fermentation behavior, and the formation of key flavor precursors under semi-dry processing conditions. The partial retention of mucilage in honey processing creates a unique biochemical environment in which enzymes such as pectinases, cellulases, proteases, glycosidases, and oxidative enzymes act synergistically to influence drying efficiency, sugar availability, and sensory development. Controlled enzymatic activity contributes to improved sweetness, enhanced fruity and caramel-like notes, greater flavor uniformity, and reduced processing defects. Although challenges related to enzyme optimization, cost, and process control remain, enzyme-assisted honey coffee processing offers a scientifically grounded approach to improving consistency and quality. Continued research into tailored enzyme systems, controlled fermentation strategies, and sustainable applications is essential to further advance the quality and reproducibility of honey-processed specialty coffees.

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