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A Review of Coffee Processing Methods and Their Influence on Aroma

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Abstract: Coffee quality is critical to the industry and is influenced by a variety of factors both before and after harvest that ensure the final expression of the product's qualification, which is based upon a number of factors including genetics, climate, agronomic practices, harvesting (mature stages), and post-harvest handling from farm to cup. This review aims to stress the importance of coffee processing and how it affects coffee quality attributes as well as fermentation techniques. Fermentation is critical in the coffee processing process, not just for removing mucilage, but also for generating essential sensory quality attributes. If fermentation takes longer than expected, bacteria can degrade the product's quality by producing off-flavors and unappealing qualities. New coffee processing procedures, such as anaerobic and carbonic maceration, have become popular recently. Only a handful of the microorganisms present in natural coffee fermentation can be used as a starting culture. Most microbes recovered from spontaneous coffee fermentation lack sensory quality-enhancing properties. Green coffee beans from farms that employ any of the following processing processes are currently fermented with chosen microbes to improve the coffee's flavor and fragrance. Other molecular sciences can help us understand the chemical components produced during fermentation and their impact on coffee quality, resulting in more reliable and complex data.

Keywords: Coffee, Fermentation, Processing, Quality

1. Introduction

Coffee processing is an important aspect of the coffee production system since it determines the quality of the product [1]. The most essential factors in the global coffee trade are physical and organoleptic attributes. According to estimates, 40% of the quality of coffee is decided in the field, 40% in primary postharvest processing, and 20% in export processing and handling, including storage [2]. This emphasizes the importance of primary processing in improving coffee's quality and value. According to Musebe, the quality of the coffee drink, which is represented by flavor and aroma, is influenced by various factors before and after harvest that ensure the final expression of the product's qualification, which, according to Musebe, is influenced by several factors, including species, climate, agronomic practices, harvesting (maturity stages), and post-harvest handling [2]. Ethiopian coffee's quality is influenced by two important factors: its geographical origin and postharvest processing processes [2].

The processing and drying procedures used by different manufacturers differ significantly, owing to technological, environmental, and economic factors as well as customer market needs [3]. Coffee's aroma and flavor are the result of interactions between volatile and nonvolatile chemical elements such as acids, aldehydes, ketones, sugars, proteins, amino acids, fatty acids, and phenolic compounds, as well as enzymes in some of these items, which produce reactions and compounds that influence the cup's taste [4]. Fermentation is a natural process in which yeasts (Saccharomyces cerevisiae) and bacteria (Lactobacillus) consume and digest sugars and acids contained in coffee cherries. As a result, these elements decompose into acids and other chemicals. As a result of this reaction, acids and alcohols are produced [5]. Anaerobic fermentation's impact on Arabica coffee quality. Sun-dried, wet (washed), and semi-washed are the three types of coffee processing.

Fermentation, drying, and storage are all part of the post-harvesting process. There are three main ways to ferment coffee: the natural technique, the wet method, and the pulped natural method [6]. (i) The natural process involves transferring freshly picked entire fruits to a drying platform, where they are fermented and dried. In (ii) the exocarp and a portion of the mesocarp are mechanically removed in the wet procedure [7]. During the fermentative process (6–72 hours), the residual mucilage is degraded and solubilized in water tanks, where the remaining mucilage is destroyed and solubilized [7]. After that, the coffee beans are taken from the tanks and sun-dried. (iii) In the pulped natural, the coffee peel and some or all of the mucilage are mechanically removed, and the coffee is sent to a drying platform where the beans are fermented and dried up to 11% moisture content [7-10].

Natural (dry) fermentation is suggested for Ethiopian coffee since it improves both the raw and roasted quality [11]. Natural fermentation is preferred in the southwest of the county due to moisture conditions (around Buno Bedele zones). Natural fermentation, on the other hand, is time-consuming, costly, batch-based rather than continuous processing promotes weight loss, and is labor-intensive when compared to demucilager. Furthermore, natural fermentation necessitates rigorous observation of temperature and fermentation time adjustments, as well as the use of high-quality equipment and a large volume of water (of acceptable quality) to produce a high-quality coffee product [11]. The length of fermentation time varies mainly as a function of the climatic conditions of the location and the condition of the crop [12].

Some Ethiopian findings on coffee processing and fermentation include the effects of shade during fermentation [11] and the fermentation period on the raw and intersenic quality of sidama and yirgacheffee coffee types [13].

However, as a result of climate variability, this has occurred throughout time, and further research into coffee post-harvest handling with coffee quality, as well as the recently introduced micro-organism inoculated fermentation, is needed. Therefore, the objective of this review is to illustrate the importance of coffee processing and how it affects coffee quality attributes, as well as fermentation techniques.

2. Coffee Processing Methods on Aroma

Coffee is produced from a pair of seeds found in the center of the coffee cherry. Following the removal of the exocarp, mesocarp, and mucilage layer, which is a colorless and viscous pectin layer lying under the mesocarp, coffee cherries are processed following one of the two processes suggested by Schwan and Wheals, depending on the place of production and species [14].

Wet or dry techniques of coffee processing exist, with the complexity and desired quality of the coffee varying [15]. The wet technique is used to process around 40% of the world's coffee, including the majority of organically grown coffees. Although particular Ethiopian or Brazilian dry-processed Arabicas are highly sought after for their distinct taste and flavor, washed coffees are typical of higher quality [16].

However, when the process parameters are properly controlled, the wet technique produces fewer faulty beans and can preserve the intrinsic attributes of the coffee beans, resulting in coffees with greater scent qualities when compared to the dry method.

The dry method, also known as natural processing, is popular for Robusta coffees, as well as in areas like Brazil and Ethiopia, where long periods of sunshine are expected. When most of the coffee cherries are ripe, they are handpicked or mechanically harvested for the dry process. As a result, the maturity levels of the collected coffee cherries are not constant. Coffee cherries are harvested and dried in layers of around 10 cm in the sun for 10–25 days, where they are continually piled and re-spread. It is well known that wet-processed Arabica coffee has higher demand and fetches a higher price on the global market, even though the traditional processing method appears to have caused river contamination in areas where wet processing is widely utilized [17].

The most significant criteria in the global coffee trade are quality and quantity, which are decided by 40% in the field, 40% in primary post-harvest processing, and 20% in secondary processing. In Ethiopian coffee is processed and exported in two ways, according to [18, 19], with natural sun-dried (70%) and washed (30%) coffees being the most common. Wet processed (washed) coffee commands a premium of more than 20% in foreign markets, while washed coffee accounts for just around 30% of Ethiopia's coffee exports [20]. Pre-and post-harvest activities, such as processing method and roasting time, have an impact on coffee quality.

2.1. The Effect of Coffee Processing Methods on Aroma

Quality variations have been identified in identical coffee samples processed using the two processing methods in parallel, indicating that processing methods influence coffee fragrance [21]. The chemical analysis of differentially processed green coffee beans revealed that wet-processed coffees had significantly lower levels of free low molecular weight sugars like fructose, glucose, arabinose, and galactose than dry-processed coffees, while the latter had significantly higher levels of glutamic and aspartic acids [22, 23].

The effects of post-harvest treatments on the amounts of aroma precursors such as 3-CQA, sucrose, and free amino acids in numerous Arabica coffee cultivars are shown in Table 1. The levels of free amino acids, reducing sugars, and phenolic compounds contained in green coffee beans of the same varietal vary significantly depending on the method of coffee processing used [24]. In addition, differences in monosaccharide content were identified in polysaccharide fractions recovered from differently treated green coffee beans (rhamnose, arabinose, galactose, and mannose). This was attributed to the variable degrees of influence that different processing methods have on the structural properties of polysaccharides and the degradation of galactomannans present in green coffee beans [25]. These are essential coffee aroma precursors, and changes in their concentrations would thus account for the observed fragrance quality disparities. While differences in the chemical compositions of wet- and dry-processed green coffee beans have been thoroughly documented, the extent to which these nonvolatile profile changes translate into aroma profile differences between differentially-processed coffees, as well as the processes that cause these changes, are less well understood. Changes in the chemical makeup of green coffee beans are most likely caused by metabolic processes that occur throughout coffee processing. Based on germination-specific isocitrate lyase (ICL) expression studies and the investigation of btubulin, a critical marker of cell division [26]. This was confirmed by evidence demonstrating an increase in free amino acid and c-aminobutyric acid concentrations in processed green coffee when storage proteins were digested to create raw materials for the germination process [22]. The reduced galactomannan concentrations in processed green coffee beans were ascribed to hydrolysis caused by endo-b-mannanases, b-mannosidases, and galactosidase [25]. Furthermore, the reduction in simple sugar concentrations, such as glucose and fructose [27, 23], might be related to sugar metabolism and inter-conversion during the seed-germination process.

Table 1. *Post-harvest interventions effect on aroma precursor composition in Arabica coffee cultivars.*

Aroma precursor		Cultivars	Conc./g 100g dry wt. of green coffee		
			Dry processing	**Semi-dry processing**	**Wet processing**
Sugars	Sucrose	Yellow Bourbon[A]	-	10.05±0.01	10.88±0.04
		Red Catual[A]	–	11.68±0.01	9.85±0.03
		Rubi[A]	–	11.98±0.02	9.16±0.05
		Topazio[A]	–	12.66±0.02	8.49±0.04
	Reducing sugars	Yellow Catual[B]	0.94±0.03^{a} –	0.52±0.02^{b}	0.14±0.01^{c}
	Total sugars	Yellow Catual[B]	7.98±0.24^{a}	7.54±0.19^{a}	8.98±0.32^{b}
Nitrogenous compounds	Caffeine	Yellow Bourbon[A]	–	1.13±0.02	1.05±0.02
		Red Catual[A]	-	1.13±0.02	1.26±0.02
		Rubi[A]		1.21±0.01	1.19±0.02
		Topazio[A]	-	1.43±0.01	1.16±0.01
	Trigonelline	Yellow Bourbon[A]	-	0.09±0.01	0.89±0.01
		Red Catual[A]	-	0.78±0.04	0.92±0.01
		Rubi[A]	-	0.74±0.01	0.80±0.01
		Topazio[A]			
		Yellow Catual[B]	1.17±0.04^{a}	1.13±0.05^{a}	1.37±0.08^{b}
	Total free amino acids	Yellow Catual[B]	1.15±0.07^{a}	0.76±0.02^{b}	0.67±0.02^{c}
	Total protein	Yellow Catual[B]	10.60±0.36^{a}	11.70±0.50^{b}	12.50±0.50^{b}
Phenolic compounds	3-CQA	Yellow Bourbon[A]	-	0.40±0.04	0.50±0.02
		Red Catual[A]	-	0.44±0.04	0.53±0.02
		Rubi[A]	-	0.45±0.02	0.42±0.02
		Topazio[A]	-	0.54±0.02	0.38±0.01
		Yellow Catual[B]	0.42±0.03a	0.41±0.01a	0.49±0.03b
	Total phenolic content	Yellow Catual[B]	3.49±0.05^{a}	3.64±0.06^{b}	3.81±0.08^{c}

The concentrations of the respective aroma precursors present in different Arabica coffee cultivars subjected to various post-harvest treatments were gathered from the following literature: A; B; C; D; E; F; F. Significant statistical differences are indicated by values with distinct lowercase letters (a–c) in the same row. "–" means that data from the literature was not accessible. 3-CQA is the abbreviation for 3-caffeoylquinic acid [26, 27].

However, the degree of metabolic processes that occur during the germination process was assessed using germination markers such as ICL and b-tubulin, which were highly dependent on the coffee processing technique [26]. As a result, it was determined that the differences in fragrance quality between wet-and dry-processed coffees were due to metabolic processes unique to each kind of post-harvest treatment [26]. The physiological mechanisms promoted by increased ICL expression during the fermentation process may thus be responsible for the improved aroma qualities of wet-processed coffees, highlighting the relevance of fermentation. Another study [28] discovered that the fermentation process in wet-processing accounts for the substantially greater scent attributes of wet-processed coffees. On coffee scent profiles, the impacts of different pulping and mucilage removal method combinations were explored. The post-harvest method, which comprised disc pulping followed by water fermentation to remove mucilage, produced coffees with desirable qualities such as fruity, floral, and caramelic overtones.

When dry fermentation was used instead of wet fermentation to remove mucilage, the coffees tasted buttery and nutty and lacked the desirable qualities. When a mechanical mucilage extractor was used in semi-dry processing, the resulting coffees exhibited unpleasant qualities such as sour, burned, and teralmond overtones. Coffees prepared from treatments that merely modified the pulping method had a very similar aromatic profile. A study like this found that the fermentation process during processing had a big influence on the coffee fragrance. It was also demonstrated that the better fragrance qualities of wet-processed coffees might be due to the formation of microbial metabolites during fermentation that was aroma precursors of roasted coffee [29].

2.2. Coffee Fermentation Effect on the Quality

Fermentation is a metabolic process that utilizes sugar in the absence of oxygen (anaerobic) or the presence of oxygen (aerobic) [30]. Complex molecules are broken down into smaller molecules in this chemical reaction, resulting in liquids and gases (volatile compounds). Because anaerobic operations are carried out in confined containers, they provide more consistent results and are easier to regulate by monitoring temperature, pH, alcohol, and other factors [31].

Fermentation may be done in three ways: wet, dry, or semi-dry. To allow spontaneous or forced fermentation to occur, the coffee fruits are treated in one of these three ways soon after harvest. Fermentation takes a different amount of time depending on the kind of processing. Regardless of the method used, the fundamental goal of the fermentation process is to remove the mucilage layer, which is high in polysaccharides (pectin), and reduce the water content of the coffee beans. Fermentation, on the other hand, has a favorable influence on coffee's quality features provided it is properly controlled [32]. Mucilage is composed of pectic components such as protopectin (33%), reducing sugars such as glucose and fructose (30%), non-reducing sugars such as sucrose (20%), and cellulose and ash (17%) [33].

Wet fermentation for arabica coffee, also known as anaerobic processing, is extensively utilized. Mature coffee fruits go through a flotation procedure right after harvest to clear debris and eliminate low-density fruits that float in the water. The coffee is then peeled (pulped) before drying, and either stored in an undersea tank for 24 to 48 hours in the sun on platforms and/or on the ground without the pulp being removed [34]. The coffee fruits are washed and sorted immediately after harvesting in dry processing, and all of the coffee is dried in the sun on platforms and/or on the ground. It entails drying the entire fruit, including the exocarp (skin), mesocarp (pulp and mucilage), and endocarp (parchment), and then labeling the fermentation process, or drying until the moisture content reaches 10%–12% [24]. The coffee fruits are washed, and low-density ones are separated immediately after harvest in dry processing, and all of the coffee is dried in coffees "unwashed or natural." [4].

Semi-dry processing is a hybrid of the two methods, in which the coffee fruits are pulped but the fermentation takes place directly under the sun on a platform [18], and the processing method chosen will be determined by economic or environmental factors, such as high relative humidity during the coffee harvest and drying period. It's also important to think about the constraints or preferences of the marketplaces where the product will be sold [35].

2.3. Mucilage Removal and Fermentation

Natural coffee fermentation is influenced by a number of factors, including the environment, pH, temperature, micro-flora, and pollution level in the water used, variety differences in the ripe cherries used for pulping, geographical and cultural origin, picking standards, and minor variations in the processing method, some of which have never been thoroughly researched. Among other aspects, the fermentation process has a significant influence on the final quality of washed coffee [36]. The method of removing the mucilage (dry fermentation, underwater fermentation, peptic enzyme-accelerated fermentation, or chemical cleaning), according to Brownbridge and Michael [37], has no effect on the quality of the liquor, and there is no evidence that one method produces significantly better liquors than another (Table 2). As a result, there is no quality benefit to building a mechanical demucilaging device, while there may be other benefits.

It has been proven that under-water soaking after "dry" fermentation, i.e., two-stage fermentation, improves the look of both raw and roasted coffees more consistently than "dry" fermentation alone [38]. Raw and roasted appearances improved after 24 hours of post-fermentation soaking compared to 8 or 16 hours. In un-replicated testing, increasing the soak time to 48 hours did not enhance the raw quality but instead degraded the roast quality. When compared to dry fermentation alone, the two-stage fermentation technique yields better raw and, more importantly, roasted coffee. When compared to dry fermentation alone, the two-stage fermentation technique yields better raw and, more importantly, roasted coffee. The effect of the two-stage procedure on liquor quality is less pronounced, but it is likely to benefit where it inhibits the development of brownness in the raw bean. Due to the quick dryness of the dry-fermenting coffee's surface, Ethiopia has proposed a modified two-stage procedure in which under-water fermentation substitutes for the traditional two-stage dry fermentation. The second step would be an underwater soaking stage that would last for 24 hours. Furthermore, the results revealed that the primary benefit of post-fermentation underwater soaking in Ethiopia is that it improves raw color and, more importantly, roast quality.

Table 2. *Displays the liquor quality of dry-fermented, under-water fermented, and NaOH-cleared coffee.*

Type of fermentation	Acidity	Body	Flavor
Two-stage fermentation 16 hours+24 hours soak	Light-medium+	Medium to light-medium	Fair/Good to FAQ
Under-water fermentation 16 hours +24 hours soak	Medium to light-medium	Medium to light-medium	Fair/Good
NaOH-Cleaned +40 hours soak	Medium to light-medium	Medium to light-medium	Fair/Good to FAQ

Source: [37]

A quicker and longer fermentation hour is necessary to reduce factory congestion and the creation of harmful off-flavors and taints such as sourness, "onion flavor," and "stinkers," which are caused by concurrent microbial and/or bean physiological and biochemical activity. An underwater fermenting technique is advised for Ethiopian circumstances [36]. Fermentation time recommendations were developed for several agro-ecologies. Any duration of mucilage degradation washed on the first, second, third, or third day following pulping that falls within the range of fewer than 24 hours, 24 to 48 hours, 48 to 72 hours, or more than 72 hours is strongly encouraged (Table 3). As extrapolated from Woelore's study [36], washed coffee-producing facilities can be arbitrarily classified as altitudinal as 1200 m and below, 1200 – 1500 m, 1500 – 1800 m, and above 1800 m for various fermenting techniques. The effect of shade on coffee cup quality during the fermenting stage has been studied [39]. The length of the fermentation phase is said to be determined by the shade level and variety. Coffee fermented in the shade takes longer than coffee fermented in the sun. The shortest fermentation duration was related to the lowest cup quality value, whereas the longest fermentation period was connected to the best cup quality value (Table 4). A positive correlation was observed between the fermentation period and cup quality. Although coffee fermented under shade takes more time, using shaded fermentation tanks helps to achieve a uniform fermentation process and better quality coffee [39].

Table 3. *Composite quality data for raw, roasted, and liquor at Limukosa, Melko, and Bebeka (*).*

Score	Limu kosa			Melko			Bebeka		
Time (hrs)	Raw	Roast	Liquor	Raw	Roast	Liquor	Raw	Roast	Liquor
24	4.9c**	5.1b	5.1d	4.6bc	5.0c	4.6b	4.6c	4.8	4.3ab
36	4.9c	5.1b	4.9cd	4.7c	4.5bc	4.5b	4.4bc	4.6	4.1a
48	4.8c	4.8ab	3.9a	4.6bc	4.1ab	4.1ab	4.5bc	4.8	4.3ab
64	4.1b	5.0ab	3.9a	4.1a	3.8a	4.0ab	4.3abc	4.9	4.2a
72/78	3.8a	4.7a	4.2ab	4.1a	3.9ab	4.3ab	4.0a	4.7	4.2a
94/96	4.2b	4.6a	4.1a	4.1a	4.1ab	4.0ab	4.2ab	4.8	4.5b
110	3.9ab	4.6a	4.6bc	4.4ab	3.9a	4.0ab	-	-	-

* Lower score denotes the better quality, ** Means followed by common letter under a column are not significantly different at 5% level.
Source: [36]

Table 4. *The interaction effect of shade and variety for fermentation period (hrs).*

Shade	Variety and fermentation duration (hrs)			Shade means
	V1 (741)	V2 (74110)	V3 (74165)	
Shaded	33.17	26.00	40.00	33.06
Unshaded	29.83	25.00	29.92	28.25
Variety means	31.50	25.5	34.94	

CV%=8.37; LSD 0.05=2.11
Source: [39]

At Jimma-Melko, researchers looked at the recirculation of coffee factory water for fermentation. It has been proven that using pulpery water as a fermentation inoculum accelerates fermentation while having no detrimental influence on coffee quality in the final cup [37-40]. Such an inoculum should be administered at a concentration of one to four water mixes because of the impact on the appearance and subsequent quality of the parchment (1:4). A stinker is a sort of coffee bean that has been too fermented and has a distracting odor that comes from the crushed raw bean. "Stink" beans have an unpleasant odor and produce acid fumes. There view suggests that inappropriate processing regimens are the primary culprit. It can be observed that regular coffee, which was previously sold for a reasonable price, is now being rejected owing to the advent of stinkers. Anaerobic fermentation and carbonic maceration are two examples of anaerobic fermentation and carbonic maceration.

2.4. Anaerobic Fermentation and Carbonic Maceration

2.4.1. Anaerobic Fermentation

Anaerobic (oxygen-free) fermentation is a relatively recent form of coffee processing that has gained traction, particularly among very high-end coffees such as competition coffees. It's important to keep in mind that anaerobic coffee fermentation arose out of need rather than a desire to alter the coffee drink. According to Borem, when arabica coffee, which originated in a subtropical climate, was introduced to tropical locations, an excessive fermentative system of the cherry fruits was discovered sequentially after harvest, severely impacting the final product's characteristics [41]. To avoid this issue, sugar-rich mesocarp extraction began. As a result, in this procedure, the focused fermentation of coffee is primarily meant to facilitate the removal of the seed mucilage layer [42]. As a result, in this procedure, the focused fermentation of coffee is primarily designed to aid in the removal of the seed mucilage layer [43]. For more than 50 years, this approach has been the industry standard throughout Central America and the Caribbean, particularly in Colombia and Costa Rica. Because of the humid atmosphere, fermentation was approved as a prerequisite for organically removing mucilage, allowing for more regulated and rapid drying. They discovered that, in addition to assisting in the drying process, the grains underwent favorable sensory alterations over time [44].

Coffee is typically fermented anaerobically in a closed tank with no oxygen present and a valve that enables carbon dioxide to escape (CO_2). Because the coffee peel and pulp are mechanically removed, leaving the mucilage adhering to the beans [45], this method gives the producer more control over the chemical processes that are taking place [46]. According to Borém, this process includes harvesting the grains, washing and separating the floating grains, which will be processed separately, peeling, pulping, or demucilating the fruits, fermentation or the use of commercial enzymes or chemical substances to remove mucilage stuck to the grain, washing to remove mucilage residue, drying, and processing the grains [41]. In this procedure, natural grains or peeled cherries are placed in hermetically sealed containers or drums that may or may not include water. This approach necessitates the use of airlock valves to remove CO_2 produced during the fermentation process and to lower internal pressure. It's quite similar to beer fermentation, except that in beer, the wort is heated to 100 degrees Celsius to destroy any naturally occurring microbes, allowing yeasts specific to each variety to be added, making the process more regulated and predictable.

There are no studies in coffee that eliminate these natural bacteria, which makes it more unpredictable, which is why regular monitoring of fermentation temperature, pH, and length is critical [44]. The anaerobic fermentation phase, according to Flanzy, requires compatibility with fixed parameters: first, the grain mass must integrate parchment coffee uniformly, with as few crushed grains, husks, and unpolished coffee as possible; second, fermentation should be completed as soon as possible after sufficient mucilage degradation; and finally, the mucilage must be removed completely after washing, before drying [47]. Producing the peeled product without attempting to remove the mucilage and with the peeled beans being quickly dried can result in a high-quality coffee. This is a relatively new processing technique, developed in Brazil, but it necessitates unique coffee handling conditions throughout the drying process to achieve the desired quality goals. It is important to remember that the mucilage attached to the grains might lead to the development of bacteria, which can harm the product's quality. Microorganisms' function in changing the sensory uniqueness of coffee and in anaerobic digestion has been a topic of debate. The most common faults ascribed to difficulties that happened during fermentation are "fermented taste," "burnt," and "sour." Fermented fruit aldehydes abound in fermented flavors. The searing flavor is reminiscent of onions, and the dark green grain has a distinct disagreeable flavor [46]. One of the factors that favor this fermenting procedure for generating peeled cherry coffees is the decrease in the space occupied on the terraces. The elimination of the peel and the lowering of processing and drying costs are two factors that favor the use of mechanical dryers [46]. In addition to improving the preservation of coffee's inherent attributes and achieving more homogenous lots with fewer faults, Furthermore, as compared to the dry procedure, the final product made by wet and semi-dry processes has better quality [45].

Controlled coffee fermentation can give drinks a characteristic sweet, citrus, fruity, and roasted aroma and flavor, increasing the product's value and consistency. We need to regulate the temperature, the water quality, the quality and health of the coffee, and the time of the fermentation process because a lack of control in the fermentation process can have a negative influence, having an aroma and flavor of moldy, phenolic, expired, wet, and fungal [46]. Because a lack of control in the fermentation process can have a negative impact, resulting in a fragrance and flavor of moldy, phenolic, expired, moist, and fungal, temperature is one of the most essential parameters in anaerobic digestion. The development and metabolic activity of microorganisms are hampered. Microorganisms that function in anaerobic environments.

2.4.2. Carbonic Maceration

The technique named "carbonic maceration" was described by Flanzy [47], and the first patent was registered by Hickinbotham [48] for use in the process of wine production to shorten processing time and generate a unique body and aroma for the final product. So, carbonic maceration is described as a process that explores the adaptability of intact fruits to a closed environment, depriving them of oxygen and filling them with carbon dioxide (CO_2). The addition of CO_2 causes the transition from aerobic respiratory metabolism to anaerobic fermentative metabolism within each fruit [49], affecting the evolution of the grapes' microbiota in the fermentation process [50]. Wines produced by carbonic maceration, according to Tesniere [49], have fruity and floral notes [51]. In general, the best fermentation conditions for wine have been obtained when this occurs between 30 and 32°C for a period of 5–8 days. Fermentation at lower temperatures (15°C) takes 20 days, demonstrating the importance of temperature and time control in the fermentation process. Change in fermentative metabolism occurs in the course of fermentation due to exposure to the

CO_2 environment. The action of microorganisms needs to be understood in this process to understand how the sensory and chemical profile can change as a result of the action of viable microorganisms during the fermentation phase. Coffee is widely accepted across the world, and even small changes in quality may have a big impact and enhance market opportunities. Coffee-processing firms may achieve this because green coffee beans are used for fermentation instead of parchment coffee (which has mucilage).

2.5. Coffee Fermentation Microbial Enzymes and Starter Cultures

During the fermentation of coffee, enzymes are produced. Over 50 yeast and bacterial species have been identified as present during coffee fermentation in previous studies [52, 53]. During the fermentation of pectinaceous sugars, the microbes in coffee fermentation contribute to the creation of ethanol, lactic, butyric, acetic, and other higher carboxylic acids, according to Silva et al. [54]. Cellulolytic Bacillus species produce a range of extracellular enzymes, according to Coughlan and Mayer [55], which may aid in the breakdown of cellulose and pectin compounds found in the skin, pulp, and mucilage of coffee cherries [56]. Pectin lyase, polygalacturonase, and pectin methylesterase are the three most essential enzymes generated by microorganisms for decomposing pectin compounds during coffee fermentation. Pectin lyase catalyzes trans-elimination of pectin, resulting in the release of unsaturated galacturonic acids [57].

2.5.1. Starter Cultures for Coffee Fermentation

A starting culture is a microbiological culture that aids in the fermentation process. Starter cultures are frequently employed in the cheese, yogurt, beer, and wine fermentation industries [58, 59]. The use of beginning culture in a controlled coffee fermentation may increase coffee quality while also providing economic benefits to producers [60]. As indicated by Corsetti, the microorganisms used for starting culture are anticipated to have particular properties, such as being nonpathogenic, nontoxigenic, and adaptable to the raw materials and procedure [61]. They should also produce sensory quality, extend shelf life, minimize processing time, and inhibit the growth of harmful bacteria associated with food. Only a few pieces of research on the use of a starting culture for coffee fermentation have been published. Agate and Bhat were the first to successfully develop a coffee fermentation starting culture. The inclusion of a combination of three Saccharomyces species (S. marxianus, S. bayanus, and S. cerevisiae var. ellipsoideus) in the fermentation process sped up the decomposition of the mucilage layer, according to their study [62].

By inoculating pectinolytic bacteria isolated from spontaneous fermentation (namely, Lactobacillus brevis L166, Erwinia herbicola C26, B. subtilis C12, and Kluyveromyces fragilis K211), researchers investigated the microbiological and physicochemical aspects of coffee fermentation [63]. The inoculation of pectinolytic bacteria, however, did not speed up the decomposition of polysaccharide components or change the beverage's organoleptic features, according to the scientists. Instead, lactic acid bacteria, according to Evangelista, should be used to keep things as near to natural fermentation as feasible [64]. Aromatic yeasts have recently been researched in coffee fermentation to create flavor during dry [64], semidry [65], and wet [66] processing. In coffee fermentation, there is normally a lot of microbial variety; however, most of these indigenous microorganisms don't have crucial features for improving the end product, thus just a few species were chosen based on their ultimate effects on the coffee's flavor and fragrance. Identification and isolation of a few species chosen for their ultimate impacts on the coffee's flavor and aroma, as mentioned above, can be employed in Ethiopia coffee.

2.5.2. Fermentation with Selected Microorganisms

Kwak studied the effect of yeast fermentation on antioxidant activity and consumer acceptance of green coffee beans [67]. They discovered that fermenting yeast for 24 hours increased antioxidant activity as well as total polyphenol and flavonoid levels. Except for one fermented coffee bean (fermented with Saccharomyces species), which earned around 39.4 percent of customer preference over the nonfermented controls, consumer approval of the fermented coffee beans was slightly lower than that of the nonfermented controls [67]. Rhizopus oligosporus is a common fungus that's utilized as a starting culture in fermented foods like soy tempeh (a traditional fermented soybean product). Extracellular enzymes, including proteases [68] and polysaccharide-degrading enzymes, are produced during R. oligosporus fermentation. The effect of R. oligosporus solid-state fermentation on the volatile and nonvolatile profile of green coffee beans was investigated. According to Lee, [certain volatiles were broken down during fermentation, whereas the creation of others might be linked to R. oligosporus' metabolism of fragrance precursors [69]. The aroma precursors in green coffee beans improved significantly after fermentation with R. oligosporus, and these compounds are responsible for the production of potent classes of odorants (pyrazines, thiols, furanones, and guaiacols) that give rise to the distinctive coffee aroma during roasting [69]. Coffee is widely accepted across the world, and even little changes in quality may make a big impact and enhance market opportunities. Coffee-processing firms may achieve this because green coffee beans are used for fermentation instead of parchment coffee (which has mucilage).

3. Conclusion

Ethiopians are well-known for exporting high-quality coffee to other countries and are the birthplace of Arabica coffee. A variety of coffee processing and quality aspects can have an impact on coffee quality. Fermentation is essential in the coffee processing process, not only for removing mucilage, but also for producing essential sensory quality attributes. In recent years, new coffee processing methods such as anaerobic and carbonic maceration have gained popularity. Because of their distinct quality and acceptance in the consuming countries, these two methods are more in demand. As a starting culture, only a few of the microorganisms found in natural coffee fermentation can be used. The use of starting cultures for coffee fermentation, on the other hand, has yet to be thoroughly investigated. The majority of the microbes recovered from spontaneous coffee fermentation do not have sensory quality-enhancing properties. Green coffee beans from farms that use any of the following processing methods are currently fermented with selected microbes to improve the flavor and fragrance of the coffee. It is the result of a fresh look at the production of distinctively flavored coffee and how to better collaborate with the coffee industry for mutual benefit.

4. Recommendations

We must contribute to the development and extension of a knowledge support system so that farmers may obtain the information they require to learn new or enhance existing processing techniques in order to increase coffee quality. Newly developed fermentation methods, such as anaerobic, carbonic maceration, and honey processing methods, could be useful for market-driven coffee processing methods in Ethiopia and around the world by this time, and research should be conducted proactively, with the results being applied to commercial farmers and boosting productivity and quality. More research is needed into the selection of nutrition microorganisms and their application to the fermentation of green coffee beans. Other molecular sciences can help researchers better understand the chemical components produced during fermentation and their impact on coffee quality, resulting in more reliable and sophisticated data. In larger investigations, integrating interdisciplinary research will be beneficial.

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