DILLA UNIVERSITY

SCHOOL OF GRADUATE STUDIES

COFFEE QUALITY AND ITS DETERMINANT FACTORS IN THE GEDEO ZONE OF SOUTHERN ETHIOPIA

M.Sc. THESIS

BY

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DECEMBER, 2025

DILLA UNIVERSITY, ETHIOPIA

Dilla University
School of Graduate Studies

Coffee Quality and Its Determinant Factors; the of Gedeo Zone, Southern Ethiopia

A Thesis Submitted to the College of Agriculture and Natural Resources, School of Graduate Studies

DILLA UNIVERSITY

In Partial Fulfillment of the Requirements for the Degree of MASTER OF SCIENCE IN (COFFEE SCIENCE AND ECONOMICS)

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DECLARATION

I hereby declare that this thesis entitled "**Coffee Quality and Its Determinant Factors the case Gedeo Zone, Southern Ethiopia"** has been carried out by me under the guidance and supervision of Alemu Dessa (PhD) and Negusie Zeray (PhD). The thesis is original and has not been submitted for the award of any degree or diploma to any university or institution.

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APPROVAL SHEET

We, the undersigned members of the Board of Examiners of the final open defense by **Tekalign Mengesha** Dogie have read and evaluated his thesis entitled **"Coffee Quality and Its Determinant Factors; the Gedeo Zone of Southern Ethiopia"** and examined the candidate's oral presentation. This is, therefore, to certify that the thesis has been accepted in partial fulfillment of the requirements for the degree of Master of Coffee Science and Economics

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BIOGRAPHIC SKETCH

Tekalign Mengesha Dogie was born on February 25, 1976, in Hama Kebele, Kochere Woreda, Gedeo Zone, and pursued his education at Hama Elementary School, Fisha Genet Junior Secondary School, and Dilla Comprehensive High School, before earning a Diploma in General Agriculture from Jimma University College of Agriculture and Veterinary Medicine (2000-2004) and a Bachelor of Arts in Accounting and Finance from Dilla University (2012-2015). His professional career began on May 9, 1996, as a Development Agent and extension worker in various kebeles of Kochere Woreda, later serving in the woreda's Agricultural Office in quality control for export commodities such as coffee, hides, and skins until 2002. Since 2002, he has been with the Ethiopia Commodity Exchange (ECX), starting as a coffee cupper until October 15, 2020, then serving as a Quality Supervisor at the Dilla branch until August 24, 2025, and currently holds the position of Coffee Quality Manager at the Head Office in Addis Ababa from August 26, 2025, to the present.

ACKNOWLEDGMENTS

First of all, I would like to very thank my Almighty God for helping me provide all research materials reaches to this final time with out any obstacle and to the final write up of the Thesis, Thanks GOD again, next to God My dearest Spouse/wife who stood by me in everything W/ro Selamawit Wakeyehu Bore Thank you from the bottom of my heart for your help and encouragement and support.

I am profoundly grateful to my advisors, Dr. Alemu Dessa and Dr. Negussie Zeray, for their exceptional support and commitment throughout my research. Dr. Alemu's guidance from the proposal stage to the final write-up, coupled with his invaluable comments and encouragement, was crucial to this study. Concurrently, Dr. Negusie's insight, professional expertise, and steadfast encouragement were indispensable to the successful completion of this work. I extend my deepest gratitude to both for their continuous technical and intellectual partnership. Thank you Very much!!

I am also highly indebted to the staffs of Dilla University Horticulture department particularly Special thanks to Mr Nuredin similarly Thank Gedeo zone Six PAs farmers support the coffee samples with least costs by discount price helped me to buy research coffee samples, Thanks all, finally thanks ECX coffee cuppers panelists they happy let me co-working with him and support during cupping session decide the quality grades.

LIST OF ACRONYMS AND ABBREVIATIONS

ANOVA	Analysis of Variance
ARDO	Agriculture and Rural Development Office
CEC	Cation Exchange Capacity
CLU	Coffee Liquoring Unit
CPPHMP	Coffee Post-Harvest Management Practices
CSA	Central Statistical Agency
Das	Development Agents
ECX	Ethiopian Commodity Exchange
FAO	Food and Agriculture Organization of the United Nations
GLM	General Linear Model
Ha	Hectare(s)
ISO	International Organization for Standardization
LSD	Least Significance Difference
MVP	Multivariate Probit Model
OM	Organic Matter
PAS	Peasant Associations
RCBD	Randomized Complete Block Design
SAS	Statistical Analysis System
SNNPR	Southern Nations, Nationalities, and Peoples' Region
SPSS	Statistical Package for the Social Sciences
USDA	United States Department of Agriculture

TABLE OF CONTENTS

DECLARATION iii
BIOGRAPHIC SKETCH v
ACKNOWLEDGMENTS vi
LIST OF ACRONYMS AND ABBREVIATIONS vii
TABLE OF CONTENTS viii
LIST OF TABLES x
LIST OF FIGURES xi
LIST OF TABLES IN THE APPENDICES xii
ABSTRACT xiii
1. INTRODUCTION 1
1.1. Background of the Study 1
1.2. Statement of the Problem 3
1.3. Research Questions 4
1.4. Objectives of the Study 4
1.4.1. General objective 4
1.4.2. Specific objectives 4
1.5. Hypotheses 5
1.6. Significance of the Study 5
1.7. Scope and Limitations of the Study 6
1.8. Organization of the Study 6
2. LITERATURE REVIEW 7
2.1. Quality Segmentation of Coffee 7
2.1.1. Exemplary quality 7
2.1.2. High-quality or premium brands 7
2.1.3. Mainstream quality 7
2.2. Theoretical Framework 8
2.3. Coffee Production in Ethiopia 8
2.4. Factors Affecting Coffee Quality 9
2.4.1. Environmental factors 10
2.4.2. Agronomic management 11

2.4.3. Post-harvesting management 14
2.5. Methodological and Analytical Approaches 19
2.6. Conceptual Frameworks of the Study 21
3. RESEARCH METHODOLOGY 25
3.1. Descriptive of the Study Area 25
3.2. Research Design and Approach 26
3.3. Data Types, Sources and Collection Methods 26
3.4. Experimental Materials 27
3.4.1. Experimental procedures 27
3.4.2. Dry processing 28
3.4.3. Wet processing 28
3.4.4. Physical and organoleptic quality analysis 29
3.5. Methods of Data Analysis 32
3.5.1. Descriptive and Inferential Statistics 32
3.5.2. Econometric model specification 32
3.5.3. Diagnostic and model validation tests 34
3.6. Variables Definition and Measurement 34
4. RESULTS AND DISCUSSION 38
4.1. Sample Households and Farm Characteristics 38
4.2. Effect of Pre- and Post-Harvest Processing Techniques on Coffee Quality 40
4.2.1. Prevalence and quality implications of processing methods 40
4.2.2. Sensory outcomes of body, defects, and overall quality assessment 42
4.2.3. Quality differentiation by geographic origin 43
4.3. Determinants of Coffee Quality 44
5. CONCLUSION AND RECOMMENDATIONS 47
5.1. Conclusion 47
5.2. Recommendations 47
6. REFERENCES 49
7. APPENDICES 58

LIST OF TABLES

Table 1: SCA quality scale level.....31
Table 2: Variables names, measurement, and hypothesized.....37
Table 3: Sample households characteristics for categorical variables.....39
Table 4: Sample households and farm characteristics for continuous variables 40
Table 5: Distribution of sample coffee producers quality grades by processing method.....42
Table 6: Mean Scores (±SE) of key cup quality attributes by processing method 43
Table 7: Quality distribution by selected geographic origins 44
Table 8: Binary logit regression results for determinants of unacceptable coffee quality.....46

LIST OF FIGURES

Figure 1: Conceptual framework of the study area.....24
Figure 2: Map of the study area 26

LIST OF TABLES IN THE APPENDICES

Annex 1: Part I. Farmers particulars 58

ABSTRACT

The Gedeo Zone, heartland of the globally renowned Yirgacheffe coffee, possesses exceptional agro-ecological potential for producing high-quality Arabica beans. Despite this international reputation and optimal growing conditions, a significant portion of coffee from this region fails to achieve its potential quality grade, representing a critical quality paradox that undermines farmer incomes and national export earnings. While previous research has documented general factors affecting coffee quality, there remains a lack of integrated analysis that simultaneously quantifies the effects of specific pre- and post-harvest practices while identifying the key socioeconomic and institutional determinants of quality failure at the producer level. This study therefore aimed to address this gap by evaluating how pre- and post-harvest processing techniques affect coffee quality, assessing the inherent quality of coffee in the Gedeo zone, and identifying the determinants of coffee quality among producers. The study employed a mixed-methods approach combining a cross-sectional survey of 138 coffee-producing households across four major woredas (Yirgacheffe, Kochere, Dilla Zuria, and Wenago), standardized laboratory analysis of physical and organoleptic properties following ECX protocols, and binary logit regression analysis to identify quality determinants. The findings reveal a stark quality paradox: despite the region's optimal agro-ecology and high adoption of pre-harvest good practices (97.1% use organic fertilizer, 94.3% practice pruning), 50.5% of farmer output was graded as unacceptable quality (ECX Grade 4 or 5). Laboratory analysis confirmed the significant superiority of washed processing, with washed coffee exhibiting substantially higher scores in key sensory attributes including acidity (8.5 ± 0.2 vs. 5.8 ± 0.3, $p<0.001$) and flavor (8.8 ± 0.1 vs. 6.5 ± 0.4, $p<0.001$). Geographic analysis revealed significant intra-zonal variability, with Yirgacheffe achieving the highest premium-grade proportion (32.5%) and lowest low-grade proportion (17.4%), while Wonago exhibited the lowest premium-grade share (20.1%) and highest low-grade proportion (33.4%). The binary logit model identified that drying coffee on bare ground (79% of farmers) was the most detrimental factor, substantially increasing the probability of poor quality. Conversely, selective picking, access to training, access to credit, and cooperative membership emerged as the most significant factors reducing the likelihood of producing unacceptable coffee. The study makes both theoretical and practical contributions. Theoretically, it advances Lancaster's consumer theory by demonstrating how institutional and socioeconomic factors operate through management practices to determine quality outcomes, addressing a notable gap in the literature concerning integrated quality determinant analysis. Practically, the findings provide actionable intelligence for critical stakeholders: for farmers and cooperatives, they validate cooperative membership as a key quality-enabler and pinpoint drying on bare ground as the most detrimental practice; for development agencies and government bodies including the Ministry of Agriculture and ECX, the evidence justifies redirecting extension services toward promoting affordable raised-bed drying technologies and strengthening cooperative infrastructure; for researchers, the integrated application of sensory analysis and econometric modeling provides a replicable framework for quality determinant studies in other Ethiopian coffee regions. The study concludes that the primary constraints to coffee quality in Gedeo are not pre-harvest agronomic practices, but rather critical post-harvest handling deficiencies, particularly drying on bare ground, compounded by inadequate institutional support. To unlock the region's full economic potential, interventions must prioritize promoting affordable raised-bed drying technologies made from local materials, strengthening cooperatives, refocusing agricultural training on practical post-harvest management, and ensuring price incentives that reward quality improvement.

Keywords: Coffee Quality, Determinants, Gedeo Zone, Post-Harvest Handling, Logit Model, Sensory Evaluation, Ethiopia.

1. INTRODUCTION

1.1. Background of the Study

Coffee is one of the most important agricultural commodities grown in the tropics and subtropics (Torrez *et al*., 2023). According to FAO (2021) reports, worldwide coffee production covers 11.1 million hectares. It is one of the most popular nonalcoholic beverages, and its popularity is growing globally (Tassew *et al*., 2021). It is also the second most important commodity traded on global markets, after crude oil. Brazil leads global coffee production with 69.9 million bags annually, followed by Vietnam (29 million) and Colombia (14.3 million). Within Ethiopia, the Gedeo Zone in the South Ethiopia Region holds a place of particular importance. It is the recognized heartland and namesake of Yirgacheffe coffee, a geographically indicated product renowned globally for its distinctive floral and citrus notes, commanding significant price premiums in the specialty coffee market (UNESCO, 2015; Teshome *et al*., 2019). Brazil exported 41 million bag coffees, Vietnam exported 23 million bags, and Colombia exported 12.5 million bag coffees, making them the top three coffee exporters from Africa. Uganda and Ethiopia export the most coffee, with 5.9 million and 4 million bag coffees exported, respectively (Statista, 2021; USDA, 2021).

More than 120 species of coffee have been identified worldwide; however, only two, *Coffea arabica* (Arabica) and *Coffea canephora* (Robusta), hold significant global economic and commercial importance (Núñez e*t al.,* 2020; Núñez e*t al.,* 2021). Among these, *Coffea arabica*, which originated in Ethiopia, accounts for approximately 70% of global coffee production (Adronikos, 2019; Belete *et al*., 2015; Girmay *et al.*, 2019; Núñez *et al.*, 2020; Scholz *et al*., 2016). Ethiopian Arabica coffee serves as the backbone of the national economy and remains the country's principal export commodity (Hordofa and Tolossa, 2020). Ethiopia is also recognized as the center of origin and genetic diversity for Arabica coffee, with beans from its various regions exhibiting distinctive flavor profiles (Moat *et al*., 2017).

According to the literature, the unique and highly valued organoleptic qualities of Ethiopian Arabica coffees are attributed to their rich genetic diversity, favorable environmental conditions, and traditional agroforestry-based production systems (Getachew *et al.*, 2020; Girmay *et al.*, 2019; Jima, 2020; Sualeh *et al.*, 2021). Factors such as altitude, soil fertility, and optimal

temperature conditions enable producers to cultivate specialty coffees characterized by superior sensory attributes (Tesfaye *et al.*, 2020).

Coffee quality, however, is a multifaceted concept encompassing different attributes across the value chain. At the exporter or importer level, quality is often associated with bean size, the number of defects, supply consistency, volume, and physical appearance. For roasters, it relates to parameters such as moisture content, origin, organoleptic properties (taste and aroma), and biochemical composition. At the consumer level, quality is primarily linked to flavor, health and alertness effects, geographic origin, and ethical or environmental considerations. Across all stages of the supply chain, quality is intrinsically connected to price (Tassew *et al.*, 2021).

In recognition of these diverse attributes, the International Organization for Standardization (ISO) established a standard for green coffee quality in 2004. This standard encompasses parameters such as defect count, moisture content, bean size, and certain chemical constituents, as well as the procedures for sample preparation and cup testing (Howard, 2010; Tassew *et al.*, 2021).

Understanding these quality attributes is underpinned by Lancaster's (1966) consumer theory, which posits that utility is derived from a product's characteristics rather than the product itself. In coffee, these characteristics, aroma, acidity, body, and flavor, are the very attributes that define its value. Therefore, a producer's decision to invest in practices that enhance these traits is an economic decision influenced by a range of socio-economic and institutional factors. The management of this quality, especially for export, is heavily influenced by national policy and institutions. The Ethiopian Commodity Exchange (ECX) plays a pivotal role by setting standardized quality grading protocols that directly determine the price farmers receive. Understanding the determinants of quality is therefore not only an agronomic pursuit but also a critical socioeconomic one, with direct implications for livelihood improvement and the effectiveness of national coffee sector strategies. While the general factors affecting coffee quality are well-documented in literature (Tassew *et al*., 2021; Yadessa *et al*., 2020), and studies by Teshome *et al*. (2019) have identified specific issues in Gedeo, a critical gap remains. There is a lack of an integrated analysis that simultaneously quantifies the effect of specific pre- and post-harvest practices and identifies the key socioeconomic and institutional determinants of quality failure at the producer level within this globally recognized zone. This study addresses

this gap by providing a comprehensive assessment of the coffee quality paradox in Gedeo: why does a region with an optimal agro-ecology for premium coffee production still see a significant portion of its output failing to meet acceptable quality standards? The findings are crucial for informing targeted interventions to enhance farmer income and sustain the global competitiveness of Gedeo coffee.

1.2. Statement of the Problem

Coffee quality is the paramount factor determining its market value, particularly for Ethiopia, where premium coffee exports serve as a critical source of foreign exchange. The Gedeo Zone, heartland of the globally renowned Yirgacheffe coffee, possesses exceptional agro-ecological potential for producing high-quality Arabica beans. However, a stark paradox exists: despite this optimal growing environment and international reputation, a significant portion of coffee produced in Gedeo fails to achieve its potential quality grade, undermining farmer incomes and national export earnings.

Coffee quality is commonly assessed through physical analysis (bean size and appearance), sensorial evaluation (cup quality), and chemical analysis of biochemical compounds associated with flavor and aroma (Bing Cheng *et al.*, 2016). Empirical studies have demonstrated that coffee quality is influenced by multiple interrelated factors. For example, Tassew *et al*. (2021) showed that location, elevation gradient, processing method, and soil quality significantly affect both physical and cup quality of coffee in southwest Ethiopia. Such studies comprehensively document the biophysical and technical factors involved. However, understanding why farmers choose certain quality-affecting practices requires a socioeconomic lens. Grounded in Lancaster's (1966) consumer theory, which posits that product value derives from its characteristics, this study posits that farmers' management decisions are shaped by a complex set of socioeconomic and institutional factors that influence their ability and incentive to produce coffee with high-value sensory attributes.

A study directly relevant to this research is Teshome *et al.* (2019), which examined quality determinants in the Gedeo Zone and identified contributing factors such as old trees, disease, and storage issues. However, a critical gap remains: there is no quantitatively robust, integrated analysis that (a) empirically tests the effect of specific practices (like drying on bare ground) on official ECX quality grades, and (b) uses econometric modeling to identify the key

socioeconomic and institutional drivers that predict the likelihood of a farmer producing unacceptable coffee. Furthermore, the role of pivotal institutions like the Ethiopian Commodity Exchange (ECX), which sets quality standards and market rules, remains underexplored as a determinant in this context.

Therefore, this study directly addresses this gap by employing a mixed-methods approach to not only assess the physical and sensory quality of Gedeo coffee but also to definitively identify the primary factors, from harvesting techniques to institutional access, that determine whether coffee from this renowned region succeeds or fails in the quality-based market. The findings are essential for developing evidence-based policy interventions that support farmers in improving quality, thereby enhancing their livelihoods and securing the premium status of Gedeo coffee in the global marketplace.

1.3. Research Questions

The research questions to be answered with this study are as follows:

1. How do the pre- and post-harvest processing techniques affect the quality of both wet and dry-processed coffee in the study area?
2. What is the inherent quality of the coffee in the Gedeo zone?
3. What are the determinants of coffee quality among the coffee producers in the study area?

1.4. Objectives of the Study

1.4.1. General objective

The general objectives of the study is to identify coffee quality and its determinant factors in the Gedeo zone of south Ethiopia.

1.4.2. Specific objectives

1. To evaluate how pre- and post-harvest processing techniques affect the quality of both wet and dry-processed coffee in the study area;
2. To assess the inherent quality of the coffee in the Gedeo zone; and
3. To identify the determinants of coffee quality among coffee producers in the study area.

1.5. Hypotheses

H_1: processing type significantly influence the coffee quality the likelihood of producing acceptable-quality coffee.

H_2: Poor drying and storage practices significantly reduce coffee quality.

H_3: Socio-economic and institutional variables indirectly affect quality through management decisions.

1.6. Significance of the Study

The most important aspect of this study is that it will be used as part of the researcher‘s graduation requirements. The study‘s additional relevance is that it provides sufficient details regarding the investigation that will assess the caliber of coffee quality in southern Ethiopia‘s Gedeo Zone. Theory-related contributions and application-related consequences are two ways to look at the relevance of this work. The significance of this study is twofold, encompassing both theoretical contributions and practical implications.

From a theoretical perspective, this study seeks to address a notable gap in the existing literature concerning the factors that influence coffee quality. By providing empirical evidence from the Gedeo Zone, the findings will enrich the current body of knowledge and serve as a valuable reference point for future research on coffee quality determinants in Ethiopia and beyond.

From a practical standpoint, the study’s findings offer actionable intelligence for critical stakeholders. For coffee farmers and cooperatives, the results pinpoint drying on bare ground as the most detrimental practice and validate cooperative membership as a key quality-enabler, providing clear priorities for investment and training. For development agencies and government bodies like the Ministry of Agriculture and ECX, the evidence justifies redirecting extension services and policy support towards promoting affordable raised-bed drying technologies and strengthening cooperative infrastructures. For researchers, the integrated application of sensory analysis and econometric modeling provides a replicable framework for quality determinant studies in other Ethiopian coffee regions, moving beyond mere correlation to identify predictive factors of quality failure.

1.7. Scope and Limitations of the Study

The scope of this study is explicitly bounded by both geography and methodology. Geographically, it is confined to the Gedeo Zone, specifically the major coffee-producing woredas of Dilla Zuria, Wenago, Yirgachefe, and Kocherie. Methodologically, its scope encompasses an integrated analysis of the factors determining coffee quality, structured around a conceptual framework that includes socio-economic, institutional, agronomic, and post-harvest management variables. The assessment of coffee quality is based on the standardized physical and sensory evaluation protocols established by the ECX, which provides a consistent and industry-recognized metric for the dependent variable.

While the mixed-methods approach provided breadth and depth, logistical and financial constraints precluded a more extensive biochemical analysis of the coffee beans, which could have provided deeper insights into the molecular basis of the observed sensory differences. Finally, because this study is based on data collected at one point in time, it can only show associations, not prove cause and effect. The logit model highlights strong and meaningful relationships, but it can't tell us for sure whether one factor directly causes changes in quality, or how long-term issues like climate change or price swings might influence results over time.

1.8. Organization of the Study

This thesis is structured into five chapters. The first introduces the research context, presents the problem statement and objectives, outlines the study's significance, and defines its scope and limitations. Chapter 2 provides a synthesis of the existing literature. Chapter 3 details the methodological framework, describing the study area, data collection protocols, sampling strategies, and analytical techniques. Chapter 4 presents and interprets the findings, including descriptive statistics and regression results. Finally, Chapter 5 offers the conclusions and recommendations.

2. LITERATURE REVIEW

2.1. Quality Segmentation of Coffee

According to the International Coffee Organization's Exporter's Guide (ICT, 2011), coffee quality can be categorized into three main commercial segments: exemplary quality, high-quality or premium brands, and mainstream quality. These categories are based on intrinsic cup characteristics, processing methods, market positioning, and target consumers.

2.1.1. Exemplary quality

This segment represents coffees with exceptionally high intrinsic value and distinctive cup profiles. Such coffees are typically available in limited quantities and are often marketed under single-estate or origin-specific names. They are usually well-processed washed coffees, including some superior washed robustas, as well as select natural coffees such as Ethiopian Harar, Yemeni Mocha, and certain Indonesian Arabicas. Exemplary-quality coffees may also include top-grade organic varieties. They are predominantly roasted by specialty or small-scale roasters and sold through exclusive outlets, such as specialty coffee shops, boutique cafés, and high-end delicatessens.

2.1.2. High-quality or premium brands

This category comprises good-cupping coffees that are well processed and properly presented, though not necessarily visually flawless. It includes well-prepared washed Arabicas, high-quality natural robustas, and certified organic coffees. These coffees are marketed both as single-origin products and as components in blends. The market for this quality band is considerably broader, encompassing much of today's specialty coffee segment. They are often produced by large multinational companies and distributed through mainstream retail channels, including supermarkets and commercial coffee outlets.

2.1.3. Mainstream quality

Mainstream-quality coffees are average-grade products that are reasonably well processed but not visually or sensorially exceptional. They typically deliver a clean, balanced, yet unremarkable cup. Despite this, such coffees form the backbone of global coffee consumption and are widely used in ready-to-drink beverages, flavored coffee products, and mass-market blends. Within today's specialty market, all three quality segments, exemplary, premium, and

mainstream, are represented, either as standalone offerings or as blended components in various product lines.

2.2. Theoretical Framework

This study is grounded in Lancaster's (1966) Consumer Theory, which posits that utility is derived from a product's characteristics rather than the product itself. In this context, coffee is not a single commodity but a bundle of sensory characteristics (aroma, acidity, body, flavor) that determine its value in the specialty market. The theory' provides a lens to model a producer's decision to invest in quality-enhancing practices as a function of their socio-economic context and institutional support. These factors influence a farmer's perceived utility (e.g., higher price, reduced risk) of producing coffee with superior characteristics. The binary logit model operationalizes this by estimating the probability (utility) of achieving acceptable quality' based on a set of explanatory variables.

2.3. Coffee Production in Ethiopia

Over four million smallholder farmers in Ethiopia are engaged in coffee cultivation, making it one of the most important agricultural activities in the country. Farmers involved in the production of stimulant crops such as coffee outnumber those engaged in fruit production (CSA, 2018). The coffee sector provides employment to an estimated 15 million Ethiopians, representing approximately 15% of the national population, across various stages of the value chain, from cultivation and processing to marketing and export. Nearly all coffee is produced on smallholder farms, typically less than half a hectare in size.

Ethiopia holds a distinguished position in global coffee production. It is the largest coffee producer in Africa, contributing about 40% of the continent's total output, and ranks as the sixth-largest producer worldwide, accounting for roughly 4% of global coffee production (Adugna, 2021). Ethiopia's unique status as the birthplace of Coffea arabica contributes to its reputation for producing some of the highest-quality coffees in the world. Arabica coffee, which constitutes over 70% of global production volume and nearly 90% of the traded market value, remains Ethiopia's dominant variety and a major source of foreign exchange earnings.

Coffee is not only vital to Ethiopia's economy but also deeply embedded in its social and cultural traditions, symbolizing hospitality and community across all regions. In 2020/21, Ethiopia

produced approximately 7.38 million 60-kg bags of coffee, continuing a steady upward trend in production that has persisted since 2002 (Sisay, 2018). According to the International Coffee Organization (ICO), Ethiopia leads Africa in coffee production, followed by Uganda (5.62 million bags) and Côte d'Ivoire (1.78 million bags) (Muhie, 2022). The country also records the fastest growth rate in coffee output in Africa, averaging 2.6% annually.

Ethiopian coffee is widely recognized for its distinctive aroma, flavor, and complex cup quality, attributes largely influenced by its diverse agroecological conditions. Coffee is predominantly cultivated at altitudes between 1,200 and 2,100 meters above sea level, in humid evergreen forest zones that provide ideal growing conditions. Despite its favorable agroclimatic potential, however, coffee production is not uniformly commercialized across all regions of the country, leaving considerable room for expansion and quality improvement in several areas. Sidama, Harar, Limu/Djimma, Tepi/Bebeka, and Yirgacheffe produce nearly 95% of Ethiopian coffee. These areas fall under the jurisdiction of the Oromia Region and the Southern Nation and Nationalities People Region (SNNPR). Although coffee is primarily cultivated in the southern and southwestern regions of Ethiopia, other areas such as Amhara, Gambella, Benishangul-Gumuz, and Tigray also possess significant potential for coffee production due to their favorable agro-climatic conditions (Muhie, 2022).

These regions offer suitable temperatures, rainfall patterns, and soil types conducive to coffee cultivation. In addition, the availability of affordable labor, particularly from unemployed rural youth, presents an opportunity for expanding coffee production. For instance, the Ayehu Coffee Farm in western Gojam (Amhara Region) demonstrates this potential. The farm exclusively cultivates Arabica coffee, which has shown high cup quality comparable to Ethiopia's renowned highland coffees such as Sidamo and Yirgacheffe, known for their distinctive aroma, flavor, and superior beverage quality (Muhie, 2022). This underscores the potential for diversifying Ethiopia's coffee production areas beyond traditional zones while maintaining high-quality standards.

2.4. Factors Affecting Coffee Quality

Coffee (Coffea spp.) is a tropical evergreen shrub cultivated for its cherries, which are processed, either by wet (washed) or dry (natural) methods, to produce green beans, the base of all coffee products. The cultivation environment, particularly the choice of land, plays a crucial role in

determining the physical and biochemical properties of coffee beans. As noted by Bossolasco (2009), land characteristics influence the intensity of agro-ecological factors such as altitude, temperature, rainfall, soil fertility, irrigation, pest management, and harvesting practices, all of which affect the growth, flowering, fruit maturation, and final cup quality (Hameed *et al*., 2018).

2.4.1. Environmental factors

2.4.1.1. Temperature and elevation

Elevation is a major determinant of air temperature, which in turn influences coffee bean development and quality (Navarro-Serrano *et al.*, 2020). Cooler temperatures at higher altitudes slow the ripening process, allowing for longer bean-filling periods and improved cup quality (Paudel *et al.*, 2021). Soil temperature, influenced by air temperature, mulching, and irrigation, also affects nutrient dynamics and biochemical composition (Onwuka, 2018).

The optimal growing temperature for Arabica coffee ranges between 18°C and 21°C; deviations from this range result in incomplete maturation (Dos Santos *et al.*, 2021). Studies indicate that increasing elevation enhances caffeine concentration while reducing chlorogenic acid content in green beans (Getachew *et al*., 2020). Variations in temperature also alter soil nutrient availability, thereby influencing plant metabolism and overall coffee quality (Getachew *et al.*, 2022).

2.4.1.2. Rain fall and relative humidity

Coffee thrives in high-altitude tropical regions with distinct wet and dry seasons. Optimal growing conditions include annual rainfall of 1,500-2,000 mm and relative humidity near saturation for most of the year (Hameed *et al*., 2018). Rainfall distribution strongly affects flowering, bean expansion, and ripening, while irregular precipitation can disrupt these phenological stages.

Arabica coffee, grown at higher elevations, requires balanced rainfall and soil moisture, whereas Robusta tolerates higher rainfall (>2,000 mm) but may suffer from reduced quality in persistently humid conditions (Adhikari *et al.*, 2020). Poor synchronization between rainfall, flowering, and harvesting can result in uneven ripening, poor drying conditions, and inferior cup quality (Rakocevic *et al*., 2020). Successful flowering requires about 30 days of moderate water stress

followed by favorable humidity (<24°C) and the absence of strong winds or extreme dryness (Hameed *et al*., 2018).

2.4.1.3. Soil

Soil type significantly affects coffee flavor, aroma, and acidity. The rich volcanic soils of Ethiopia and other tropical regions produce beans with bright acidity, a highly prized attribute in specialty coffee (Prates Junior *et al.,* 2021). However, excessive acidity can lead to sourness, which is undesirable. Coffees grown at high altitudes on mineral-rich volcanic soils tend to exhibit enhanced acidity and complex flavor profiles (Abebe and Abebe, 2023).

2.4.1.4. Socio-economic and livelihood

Socio-economic conditions influence coffee quality through their effects on technology adoption, farm management, and resource availability. For perennial crops such as coffee, adoption of improved technologies is often constrained by delayed returns and limited market access. Factors such as credit access, farm size, input availability, and extension services play pivotal roles in influencing adoption (Mulugeta, 1999).

Studies from western Ethiopia (Negussie *et al*., 2008; Anwar, 2010) show that farmers' perceptions and adoption of quality-improving practices are positively influenced by education, training, and proximity to research centers, while challenges such as lack of labor, tools, and financial resources hinder proper farm management. Furthermore, poor infrastructure, limited credit services, and low institutional support have been identified as key constraints to quality production and marketing (Elias, 2005; Belay *et al.,* 2016).

2.4.2. Agronomic management

2.4.2.1. Variety selection

Variety selection is fundamental to achieving high yields and superior coffee quality. Both Coffea arabica and Coffea canephora (Robusta) are cultivated globally, each offering distinct characteristics. Arabica is valued for its mild flavor, aromatic complexity, and high cup quality, while Robusta is known for its disease resistance, higher caffeine content, and role in espresso and instant coffee blends (Ahmed *et al*., 2021).

Arabica varieties are grouped into wild types, introgressed lines (e.g., Timor hybrids), and non-introgressed types (Typica and Bourbon), whereas Robusta includes Guinean and Congolese

genetic groups (Leroy *et al.*, 2006). The performance and flavor profile of a given variety depend heavily on regional environmental conditions, soil characteristics, and management practices (Goldstein, 2011; Hameed *et al.*, 2018).

Despite the disease resistance of hybrid varieties such as the Hybrid of Timor, many producers in Central America and Africa still prefer traditional varieties like Caturra, Bourbon, Pacamara, and Catuai for their proven yield stability and superior cup quality (Turreira-García, 2022). Understanding the biochemical composition of these varieties is therefore essential for enhancing quality and sustainability in the specialty coffee sector.

2.4.2.2. Shade tree management

Traditional organic coffee systems emphasize shade-grown cultivation, which enhances ecological stability and long-term productivity. Shade trees regulate sunlight, reduce soil erosion, improve organic matter content, and create microclimates unfavorable to pests and diseases (Geeraert *et al*., 2019; Lashua, 2016).

During flowering and fruit development, Arabica coffee demands substantial carbohydrates from leaves and stems. Shade management helps mitigate physiological stress by stabilizing temperature, reducing periodic yield fluctuations, and maintaining soil fertility, thus ensuring sustained yield and cup quality over time. Coffee branches become overbearing and die as a result. Furthermore, shading causes coffee berries to mature later, resulting in better bean filling and larger bean sizes, and thus better coffee quality (Alemu, 2015; Hundera, 2016).

According to Adugna and Paul (2010), coffee plants cultivated under shade trees tend to produce larger and heavier cherries with superior bean quality compared to those grown under direct sunlight. Moreover, shaded coffee plants exhibit enhanced biochemical and physiological capacity for greater dry matter accumulation, contributing to the sustainable maintenance of high yields over time. Growing coffee under shade trees could make other sources of income such as fruits, fuel wood, and timber more socially acceptable, economically viable, and environmentally sustainable (Bote and Vos, 2017; Meylan *et al*., 2017).

2.4.2.3. Fertilization (soil nutrients)

Among the many causes of poor coffee cup quality, One of the major factors affecting coffee quality is under- or non-fertilization of coffee fields. Interestingly, there exists a clear and

positive relationship between the organoleptic (sensory) attributes of coffee and low soil fertility. To address the issue of low soil fertility, the traditional methods of fertilization for coffee fields are the same, namely organic and inorganic or mineral fertilization (Merkebu Getachew *et al*., 2023; Howard, 2010). This component of coffee production is significantly influenced by topographic conditions, management practices, organic matter and herbicide applications, shade, rainfall or irrigation, planting and intercropping patterns, and agroforestry systems. These factors collectively affect soil properties such as organic matter content (OM), moisture availability, porosity, aeration, texture, acidity, cation levels, cation exchange capacity (CEC), and microbial diversity. However, most existing research on coffee soils and fertilization has primarily focused on yield, growth performance, soil fertility, erosion, acidity, and toxicity. As a result, there remains a notable gap in the literature concerning the direct relationship between soil nutrients or fertility and the cupping (sensory) quality of coffee (Hameed *et al*., 2018; Kremen and Miles, 2012).

Ensuring a proper and sustainable supply of nutrients is essential, as plant nutrition directly determines the size (grade) and biochemical composition of coffee beans. Even when organic matter or litter is incorporated into the soil, it often cannot provide sufficient long-term nutrient availability. Therefore, the judicious use of inorganic fertilizers is required to meet crop demands. A one-hectare plot of mature, highly productive coffee typically requires about 135 kg of nitrogen (N), 34 kg of phosphorus (P_2O_5), and 145 kg of potassium (K_2O). The precise nutrient requirements, however, vary by region and depend on factors such as soil topography, rainfall, agro-ecological conditions, cropping density, and management practices. Both macro- and micronutrients, including N, P, K, Ca, Mg, S, Fe, Mn, Zn, Mo, and C, play distinct physiological roles (Hameed *et al.,* 2018).

In forest coffee systems, macro-nutrients such as phosphorus (P) and potassium (K), along with finer soil textures (silt and clay), have been found to correlate positively with improved cup quality. Similarly, higher soil concentrations of magnesium (Mg), manganese (Mn), zinc (Zn), and optimal pH levels were associated with enhanced coffee aroma (Tassew *et al.,* 2021).

Although micronutrient levels are generally adequate for plant growth, fluctuations in macronutrient availability can disrupt the balance of micronutrients, sometimes leading to toxicity (e.g., aluminum toxicity). Nitrogen (N), in particular, is critical because it forms

chlorophyll, supports photosynthesis, and promotes vegetative growth, flowering, and fruit-bearing. It also influences the synthesis of amino acids, which directly affect the biochemical and sensory quality of coffee. Inconsistent nitrogen supply may alter amino acid and protein composition, thereby reducing beverage quality. Nitrogen further maintains the fruit-to-leaf ratio and helps prevent dieback diseases. Moreover, soil nitrogen content is positively correlated with organic matter levels, and organic inputs rich in nitrogen stimulate microbial activity and diversity, while also reducing nutrient leaching (Alloway, 2008; Hameed *et al*., 2018). The data showed that increasing soil N has a positive relationship with yield and that increasing soil Ca(O) increases soil N uptake efficiency, implying that soil Ca concentration can be used as a "marker" for yield (Kiani *et al*., 2021).

2.4.3. Post-harvesting management

2.4.3.1. Harvesting (strip and selected)

The primary factor influencing natural coffee quality is the method of harvesting. Traditional hand-picking and manual husbandry practices, rather than mechanical harvesting, yield the highest-quality green coffee by minimizing the proportion of defective beans in harvested batches. Coffee harvesting is one of the most labor-intensive and challenging stages in green coffee production and processing. The two primary harvesting methods are selective picking and strip picking (Melese, 2019).

Selective picking involves the careful hand-picking of only fully ripened cherries for processing. Although this method is labor-intensive and costly, it produces superior-quality Arabica beans with exceptional cup characteristics. In contrast, strip picking, performed either manually or mechanically, harvests all cherries simultaneously, regardless of their ripeness level (ripe, overripe, or underripe). While selective picking is ideal for producing premium-grade coffee, mechanical or strip picking is more practical and cost-effective in regions like Brazil, where coffee cherries tend to ripen uniformly (Erkan and Dogan, 2019). The extent of picking times for the selective picking method is determined by species, farm, tree, and agroecological conditions. Typically, the selective picking method requires three to seven harvests per season. Harvesting cherries at their peak ripeness is the most critical factor in determining the final cup quality of Arabica coffee. The physical and biochemical cup quality of coffee is best when mature Arabica

red cherries are picked early. The caffeine content was also low in both overripe and underripe cherries (Hameed *et al*., 2018).

Selective-picking cherries are used for wet processing when they are fully mature, whereas cherries maturity at different stages are recommended for further drying. Harvesting methods, whether selective or indiscriminate, significantly influence dry bean size, weight, color, primary and secondary defects (such as full black, fungus-infected, insect-damaged, or foreign matter), as well as aroma, roast, and cup quality (Ameyu, 2017). Selective picking at peak maturity, when combined with proper postharvest handling, produces the largest and most uniform beans. In contrast, strip picking and other suboptimal harvesting practices reduce bean quality and result in uneven bean size distribution. Uniform beans are essential not only for achieving premium prices in international markets but also for ensuring a consistent roast, free from under-roasted, over-roasted, or burnt beans.

Coffee harvested selectively typically reaches Grade 2 quality, equivalent to specialty coffee, whereas strip-harvested coffee often falls to Grade 5, reflecting lower quality. Selective picking also ensures uniform bean weight and color, as fully mature cherries are approximately 20% heavier than under-ripe cherries. Inclusion of underripe or overripe cherries leads to variation in bean weight and uneven roast color (Hameed *et al.*, 2018).

Primary and secondary defects contribute to off-flavors in coffee. Washed coffee from selectively harvested cherries consistently exhibits the lowest incidence of such defects, whereas strip harvesting often collects broken, faded, insect- or fungus-damaged cherries. Properly harvested and postharvest-managed cherries also produce superior aroma and cup quality (Hameed *et al*., 2018; Worku, 2019). Furthermore, selectively harvested beans demonstrate greater stability during roasting, exhibiting minimal roast volume changes and reduced roasted bean weight loss, whereas strip-harvested coffee shows the highest variability in roast volume and weight loss. This is due to nonuniform cherry size, which increases the possibility of moisture and internal composition losses, volatile compound losses, and gas expansions (Hameed *et al.*, 2018).

High coffee acidity is considered premium and commands a premium price. High coffee acid has a pleasing, sharp, snappy flavor, giving the resulting beverage a more intense aroma and higher quality. High-quality, acidic coffee is primarily achieved through selective harvesting

followed by wet (washed) postharvest processing. A key factor in this quality is the removal or breakdown of the mucilage layer covering the parchment during fermentation in the wet processing method, which enhances cup characteristics (Hameed *et al.*, 2018; Sualeh *et al.*, 2021). Studies have shown that selective picking combined with wet processing produces coffee with superior cup attributes, including bright acidity, full body, and distinct flavor. The enhanced flavor profile is largely attributed to the fact that fully mature cherries contain the highest sucrose content, contributing to elevated Brix levels and other optimal flavor compounds (Bastian *et al.*, 2021; Hameed *et al.*, 2018).

The choice of harvesting method is influenced by multiple factors, including the postharvest processing method (dry, wet, or semi-washed), availability of skilled labor, climatic and seasonal conditions, market demands and profitability, coffee variety, local policies, and the socioeconomic status of the farmer. To maximize the percentage of mature cherries, selective picking is usually used in conjunction with wet or semi-wet processing (Gather, 2022). The method of harvesting is also not chosen logically and may be influenced by long-established practices and traditions. Strip harvesting is used in Arabica natural coffee countries, whereas selective hand picking is used in washed coffee countries. Large wheeled or tractor-driven harvesters have been used for strip harvesting over the last three decades, potentially causing plant damage. Self-propelled harvesters are equipped with built-in winnowing systems that not only collect coffee cherries but also remove dust, dirt, leaves, sticks, sand, and other foreign materials. However, growers must remain cautious of the limitations of mechanical and strip harvesting, particularly the inability to effectively separate immature or damaged cherries from fully ripe, mature cherries, which can negatively impact overall coffee quality (Hameed *et al.*, 2018).

2.4.3.2. Processing (wet and natural)

The method of processing has a major influence on Arabica coffee quality. Wet (washed) processing produces coffee that is highly aromatic with bright acidity and astringency, whereas dry (natural) processing tends to produce coffee with more body but lower aroma and acidity. The higher acidity in washed coffees is partially masked in naturally processed coffees due to their fuller body (Banti and Abraham, 2021). Sensory evaluations consistently show that dry-

and wet-processed coffees from the same origin can be distinguished with high significance (Selmar *et al.*, 2001; Toledo *et al.*, 2016).

In Ethiopia, dry-processed coffee accounts for more than 60% of Arabica production. While processing method and moisture reduction are critical postharvest operations, the dry process is more vulnerable to inconsistencies due to variable climatic conditions, often resulting in uneven drying and lower cup quality. Consequently, the literature generally recommends wet processing for consistently high-quality coffee (Ameyu, 2017). Research at Awada Coffee Research Station reported that dry-processed coffee exhibited high acidity and medium-to-full body when sun-dried, although it had lower aroma than wet-processed beans (Banti and Abraham, 2021). The variability in ripeness of cherries collected for dry processing also contributes to inconsistent quality.

Wet processing, although more labor-intensive, generally produces superior-quality coffee. It involves selective harvesting of fully ripe cherries and underwater fermentation, which enhances acidity by breaking down the mucilage layer covering the parchment. The fermentation process, driven by yeasts, produces organic acids and volatile compounds that are critical to the final aroma and flavor profile of washed Arabica coffee (Banti and Abraham, 2021; Haile and Hee Kang, 2020). Over-fermentation, however, can lead to microbial inhibition, off-flavors, and stinky beans, which deteriorate cup quality.

2.4.3.3. Drying

Drying is regarded as a crucial step in maintaining coffee quality because moisture levels above 12% can promote microbial growth and mycotoxin formation (Reh *et al*., 2006). The primary goal is to reduce the moisture content of freshly pulped coffee, which is approximately 55%, to an optimal storage level of about 11%. Proper drying ensures safe storage, efficient hulling, and optimal roasting, all of which are essential for producing high-quality coffee. Sun drying is primarily used in most developing countries, primarily by producer organizations and cooperatives, coffee is typically spread on wire mesh tables and sun-dried for about two weeks until fully dry. Only a few commercial companies employ mechanical drying methods (Mutua, 2000). Over-drying on the surface can cause irreversible shrinkage of the beans, negatively affecting their quality, preventing moisture from moving outward from within the bean. Worse, the bean‘s appearance may become pale and bleached, indicating flavor deterioration. Field

evidence has shown that when drying is done too quickly at excessively warm temperatures, the valuable cup flavor of coffees that would otherwise be considered excellent is largely lost (Raghu Nath Subedi, 2010). The degree of coffee bean dryness is commonly assessed using two methods: dental and digital. The dental method involves peeling the parchment of a single bean and biting it with the incisors. If the bean is easily dented or cut, it is considered not dry; if a firm bite only slightly dents the bean, it is considered dry. However, this method is highly subjective and unreliable. In contrast, a properly calibrated digital coffee moisture meter is the most accurate tool for determining coffee moisture content (Tesfa, 2019).

2.4.3.4. Storing

Proper storage is a critical step because dried coffee can readily absorb moisture or off-flavors from its environment, leading to quality degradation. Once the beans reach the desired moisture content, they should be stored in a cool, dry place, away from contaminants such as soil, smoke, animals, or other organic matter. Moisture levels should be regularly monitored to ensure stabilization.

Due to fluctuations between supply and demand, coffee is often stored for extended periods, which can affect cup quality. Aged green coffee, stored for long durations, may lose acidity, a key attribute for specialty coffee classification (Wintegens, 2004). Storage conditions, including duration, temperature, and relative humidity, significantly influence both the physical appearance and sensory quality of raw and roasted beans (Yigzaw, 2005). Long-term storage under high humidity and warm conditions increases bean moisture, accelerating quality deterioration. Even under optimal conditions, aging can lead to oxidation of fats, causing off-flavors.

For extended storage, the recommended conditions are 20°C and 65% relative humidity. Storage is among the most critical stages in agricultural commodity processing, as it preserves bean integrity, quality attributes, and food safety. Coffee beans are living organisms, and their viability is highly dependent on storage conditions. Toxic substances that develop during improper storage can pose health risks to consumers. Under normal conditions, the generally accepted storage period for green coffee is one year (Tesfa, 2019; Adam and Anwar, 2010).

2.4.4 Harvest and post-harvest factors

In synthesis, the research clearly shows that what happens after harvest plays a major role in determining coffee quality. But there‘s still more to learn. First, although many studies point out

the importance of practices like selective picking or proper drying, few have actually measured how much each factor matters when considered together. Second, most studies in Ethiopia focus mainly on technical or environmental factors. While they do mention institutional elements like cooperative membership or access to credit, these are often treated as side notes rather than key drivers.

This study fills both gaps. By using an econometric model, it measures how much each technical and institutional factor contributes to the risk of producing poor-quality coffee. In doing so, it puts institutional support and farmer decision-making at the center of the conversation, not just their farming techniques.

2.5. Methodological and Analytical Approaches

Empirical studies investigating the determinants of coffee quality have employed a range of methodological approaches, each with distinct strengths and limitations. A critical review of these approaches is essential to justify the analytical strategy adopted in this study.

Mixed-Methods Approaches: Most quality determinant studies combine cross-sectional household surveys with laboratory analysis of coffee samples. Tassew *et al.* (2021) employed this approach in the Kafa Biosphere Reserve, using structured questionnaires to collect data on farm management practices alongside physical and sensory evaluation of coffee samples following ECX protocols. Similarly, Teshome *et al.* (2019) utilized household surveys in the Gedeo Zone to identify quality-related practices, complemented by coffee sample analysis. The strength of this mixed approach lies in its ability to link farmer characteristics and practices with objective quality outcomes. However, a limitation is that such studies often remain descriptive, identifying correlations without rigorously testing the relative importance of multiple factors simultaneously.

Sensory Evaluation Protocols: Standardized cupping procedures following ECX or Specialty Coffee Association (SCA) protocols are widely used to measure the dependent variable, coffee quality. Worku (2019) demonstrated the reliability of these protocols for Ethiopian coffees, showing that trained cuppers can consistently differentiate quality grades. The advantage of this approach is its industry recognition and direct economic relevance, as ECX grades determine market prices. The limitation is that sensory evaluation, while standardized, retains an element of subjectivity, necessitating the use of multiple panelists and replication to ensure reliability.

Econometric Modeling Approaches: When coffee quality is measured as a categorical outcome (e.g., graded categories), researchers commonly employ qualitative response models. Belay et al. (2016) used binary logit regression to identify factors affecting coffee quality in Ethiopia, finding that processing method, drying surface, and storage conditions were significant determinants. Ameyu (2017) employed both binary and multivariate probit models to analyze the influence of harvesting and post-harvest practices on coffee quality in eastern Ethiopia.

The choice between logit and probit models warrants careful consideration. Both models yield similar results in most applications, as their cumulative distribution functions (logistic vs. normal) are closely related (Greene, 2018). However, each has distinct advantages:

Probit Model: Assumes a normal distribution of the error term and is theoretically appealing when the underlying decision process is believed to follow a normal distribution. It performs well with large samples and when extreme values are present.

Logit Model: Assumes a logistic distribution, which has slightly heavier tails than the normal distribution. Its primary advantage is computational simplicity and interpretability, as coefficients can be easily transformed into odds ratios (Wooldridge, 2020). The logit model is particularly suitable for policy-oriented research because odds ratios provide intuitive measures of how changes in explanatory variables affect the probability of an outcome.

Some studies, such as Getachew *et al.* (2023), have employed multivariate probit (MVP) models to analyze multiple, interrelated adoption decisions simultaneously. While MVP models account for correlation among multiple dependent variables, they are computationally intensive and require larger sample sizes. For a single binary outcome (acceptable vs. unacceptable quality), the additional complexity of MVP is unnecessary.

Justification for the Current Study's Approach: Based on this methodological review, the present study adopts a binary logit model for several reasons. First, the dependent variable, coffee quality status, is dichotomous (acceptable = ECX Grades 1-3; unacceptable = Grades 4-5), making binary choice models appropriate. Second, the logit model's odds ratio interpretation aligns with the study's policy-oriented objectives, allowing clear quantification of how factors such as drying method or cooperative membership affect the likelihood of producing acceptable coffee. Third, the logit model is computationally efficient and widely used in agricultural economics research, ensuring comparability with existing Ethiopian studies (Belay et al., 2016;

Ameyu, 2017). Fourth, diagnostic tests (discussed in Section 3.6.3) confirmed that the logit specification adequately fits the data.

This study follows the proven approach of combining structured household surveys, professional laboratory cupping following ECX standards, and binary logit regression analysis. What distinguishes it from previous work is its integrated focus on the Gedeo Zone, a globally recognized but understudied coffee-producing area, and its explicit testing of both technical and institutional determinants within a single analytical framework.

2.6. Conceptual Frameworks of the Study

The conceptual framework for this study is designed to illustrate the causal pathways through which various factors influence coffee quality in the Gedeo Zone. Unlike a simple listing of variables, this framework specifies the hierarchical and sequential relationships among determinants, culminating in the final quality outcome.

he framework posits that coffee quality is not directly determined by any single factor but is the result of a multi-stage causal chain. Specifically, institutional and socio-economic factors serve as foundational enabling conditions that shape farmers' capacity to implement optimal agronomic and post-harvest management practices. These management practices, in turn, directly determine the physical and sensory attributes of the coffee, which ultimately translate into its official quality grade (acceptable vs. unacceptable).

The causal relationships are specified as follows:

Stage 1: Foundational Factors (Enabling Conditions)

Institutional and Socio-Economic Factors (e.g., access to training, credit, cooperative membership, education level, cash constraints) form the external context in which farmers operate. These factors do not directly alter coffee beans but rather enable or constrain farmers' ability to adopt quality-enhancing practices. For instance:

- **Access to training** increases knowledge of proper harvesting and drying techniques.
- **Access to credit** provides liquidity to invest in raised drying beds or hire labor for selective picking.

- **Cooperative membership** offers access to shared processing facilities and collective marketing.
- **Cash shortage at harvest** may force farmers to strip-pick and sell immediately, bypassing quality protocols.

Stage 2: Proximal Determinants (Management Practices)

Agronomic and Post-Harvest Management Practices are the direct actions farmers take that physically affect the coffee beans. These include:

- **Pre-harvest practices:** pruning, shade management, fertilization, disease control, and coffee tree age management.
- **Harvest practices:** selective picking vs. strip picking, fruit maturity at harvest.
- **Post-harvest practices:** processing method (washed vs. natural), drying surface (raised beds vs. bare ground), storage conditions, and storage duration.

These practices directly influence the biochemical and physical integrity of the coffee beans.

Stage 3: Mediating Variables (Coffee Attributes)

The management practices described above produce measurable *coffee attributes*, including:

- **Physical attributes:** bean size, moisture content, defect count, uniformity.
- **Sensory attributes:** acidity, body, flavor, cleanliness, aroma.

These attributes are not the final outcome but rather the mediating characteristics that determine market valuation.

Stage 4: Final Outcome (Quality Grade)

The combination of physical and sensory attributes determines the coffee's *official quality grade* according to ECX standards. For this study, quality is operationalized as a binary outcome:

- **Acceptable Quality:** ECX Grades 1–3 (specialty and premium commercial grades)
- **Unacceptable Quality:** ECX Grades 4–5 (lower commercial grades with significant defects)

Theoretical Grounding: This framework is consistent with Lancaster's (1966) consumer theory, which posits that utility is derived from product characteristics rather than the product itself. Here, farmers' management decisions are motivated by the desired characteristics (sensory attributes) that command premium prices. However, their ability to produce these characteristics is mediated by the enabling factors in Stage 1.

Key Causal Pathways:

1. **Institutional Support → Better Practices → Higher Quality:** Farmers with training, credit, and cooperative membership are more likely to adopt selective picking, raised-bed drying, and wet processing, resulting in superior sensory attributes and acceptable quality grades.
2. **Cash Constraints → Poor Practices → Lower Quality:** Farmers facing cash shortages at harvest are more likely to strip-pick immature cherries, dry on bare ground, and sell quickly without proper storage, leading to higher defect counts and unacceptable quality.
3. **Tree Age → Bean Quality → Grade:** Older coffee trees, unless properly managed, produce lower-density beans with inferior cup quality, increasing the probability of downgrading.

Distinction from Previous Frameworks: Unlike Teshome *et al.* (2019), which treated institutional factors as peripheral, this framework positions them as central determinants that operate *through* management practices. Unlike Tassew *et al.* (2021), which focused on biophysical factors, this framework explicitly models the socio-economic drivers of practice adoption.

Visual Representation: Figure 1 depicts this framework graphically, with arrows indicating the direction of causality from foundational factors → management practices → coffee attributes → final quality grade. This hierarchical structure enables the empirical testing of both direct and indirect effects using the binary logit model.

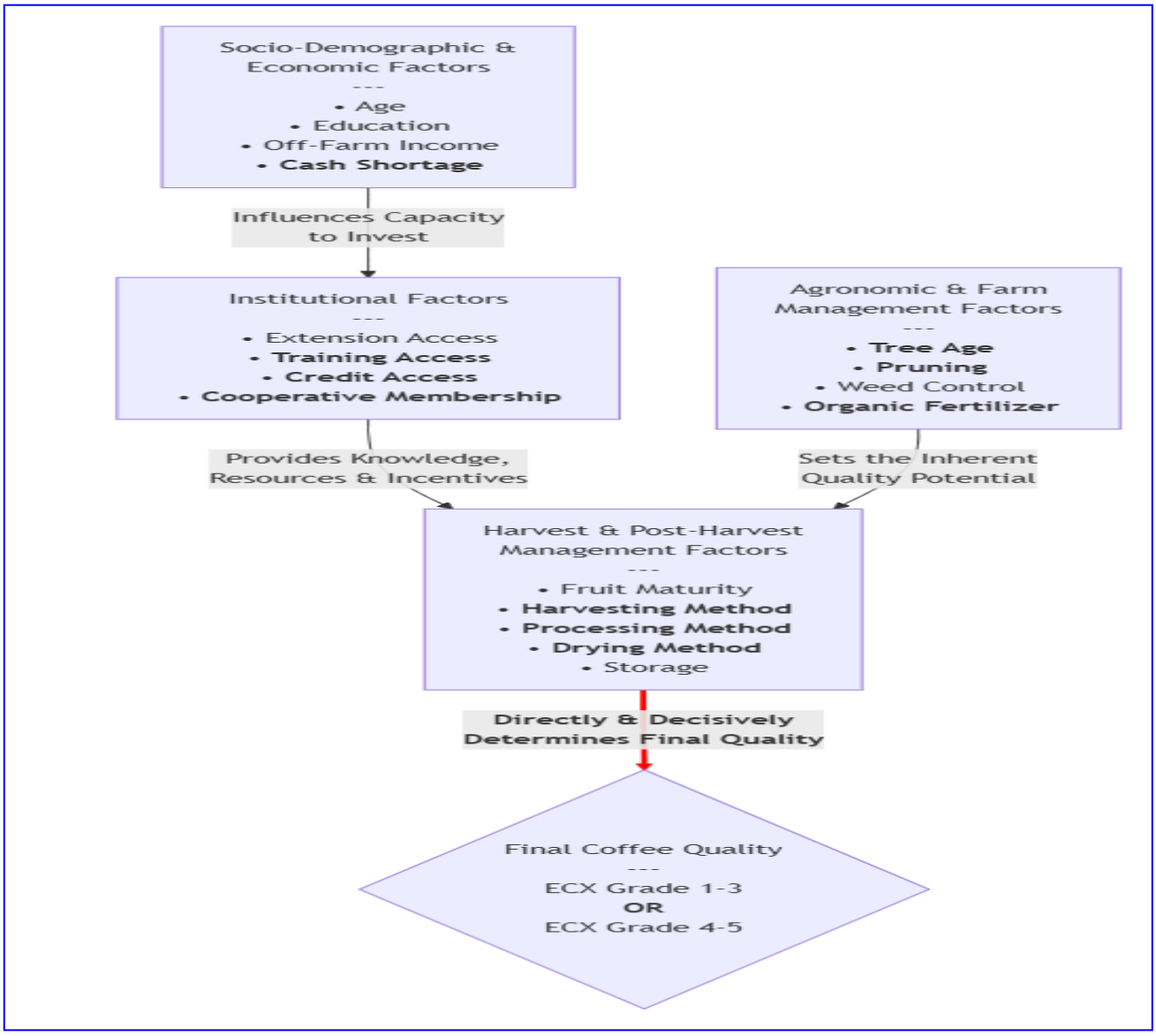

Figure 1: Conceptual framework of the study area

3. RESEARCH METHODOLOGY

3.1. Descriptive of the Study Area

The Gedeo Zone, a distinctive and culturally significant administrative unit within the South Ethiopia Region, is comprised of six rural districts, Dilla Zuria, Wenago, Yirgachefe, Kocherie, Bule, and Gedeb, with its capital in Dilla. The Gedeo Zone is precisely located between 5°50’ and 6°25’ N and 38°10’ and 38°30’ E, bordered by Sidama Zone to the north and Oromia Region to the east, south, and west. Its dramatic topography is defined by the eastern escarpment of the Main Ethiopian Rift, creating a steep altitudinal gradient that plunges from 2,993 m.a.s.l. at its peak in Bule down to 1,200 m.a.s.l. near Lake Abaya (Teshome *et al*., 2019). Home to the Gedeo people, the zone is famed for its UNESCO-registered agroforestry system, a multi-tiered practice that integrates native trees with the renowned Yirgachefe coffee and the staple enset crop.

According to CSA, (2023) national statistical abstract, which projects populations based on the 2007 national census, the population of Gedeo Zone is estimated to be approximately 1.4 million people. The sustainable system of the zone supports a high population density, whose livelihoods and the local economy are profoundly intertwined with the production of this premium coffee, making the community both a guardian of this heritage and highly dependent on its success (Bishaw *et al.*, 2013; UNESCO, 2015). The mean annual temperatures (17–22.4°C) and high rainfall (1200–1800 mm) (Bishaw *et al*., 2013; Tolera *et al*., 2021).

The Gedeo Zone is of significant national and international research interest as a recognized agrobiodiversity hotspot, being the heartland of premium Yirgachefe coffee and a model of sustainable agroforestry. This socio-economically vital region is profoundly sensitive to global market fluctuations and climate change, while also facing environmental pressures from population growth and land fragmentation that threaten its ecological resilience, making it an ideal case study for climate impact on high-value agricultural systems (Tolera *et al*., 2021; Teshome *et al.*, 2019).

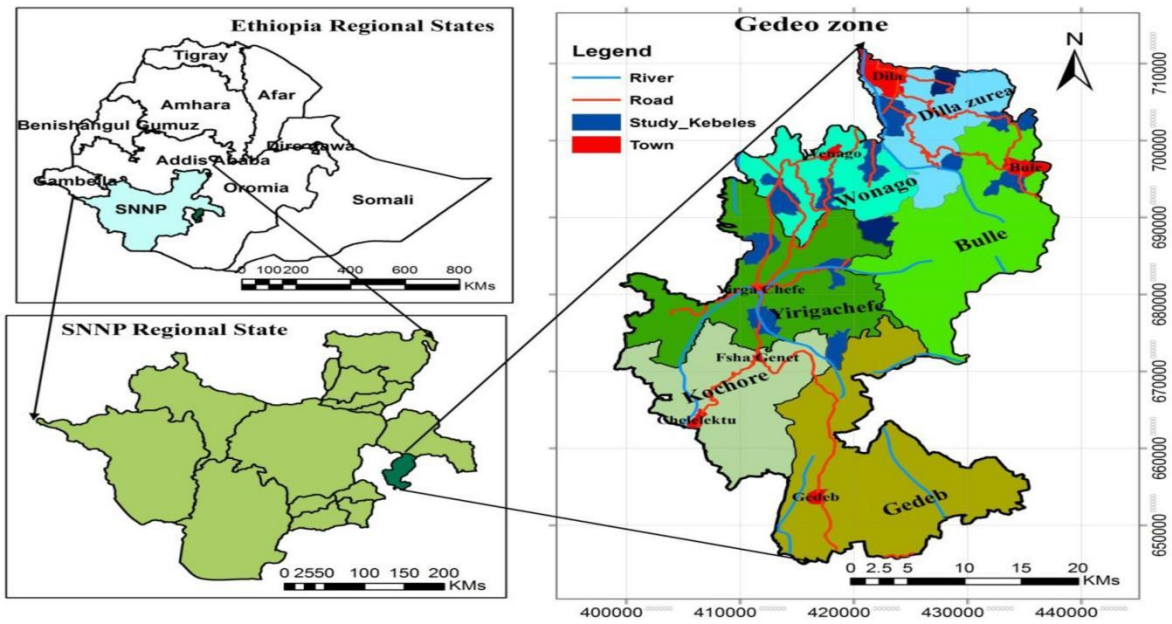

Figure 2: Map of the study area

3.2. Research Design and Approach

This study employed an explanatory sequential mixed-methods design. A cross-sectional survey was used to collect quantitative data on farmer practices and contexts, which was then explained and enriched through qualitative data from focus group discussions and key informant interviews. The laboratory experiments provided objective, quantitative measures of the dependent variable, coffee quality. This design was chosen to provide both breadth in identifying determinants and depth in understanding the underlying reasons for observed practices, aligning with a post-positivist research philosophy that seeks objective evidence while acknowledging the complexity of social contexts.

3.3. Data Types, Sources and Collection Methods

This study utilized both primary and secondary data to ensure a comprehensive analysis. Primary data were collected directly from coffee producers using semi- structured questionnaires. Which featured a combination of closed-ended and open-ended questions to gather both quantitative and qualitative insights. Additionally, secondary data were incorporated including a record of coffee quality metrics sourced from the ECX Dilla center. Sampling Procedures and Sample Size

A multi stage sampling procedure was employed to ensure the collection of reliable and representative data from the target population. In the first stage, a purposive sampling technique

was applied to select four major coffee-producing *woredas* (Kochere, Dilla Zuria, Wenago, and Yirgacheffe). This selection was justified by the need to delineate the primary sampling frame, the selection of these four woredas was purposive, based on two criteria: they are the core geographic indication area for Yirgacheffe coffee and represent the highest volume of coffee trade through the ECX Dilla center, ensuring data relevance and richness. In the second stage, three kebeles were randomly selected from each *woreda* using a systematic random sampling approach. This was designed to enhance the geographic representativeness of the study and reduce selection bias. In the final stage, 138 coffee-producing households were randomly selected from comprehensive household lists obtained from local government and extension offices. This approach ensured that the final sample was unbiased and that the data collected possessed a reasonable degree of generalizability within the defined parameters of the study.

The sample size was determined using Green's (1991) rule of thumb ($n \geq 50 + 8m$), which recommends a minimum sample size of 138 for 11 independent variables. Finally, probability proportional to size sampling was used to distribute the sample across kebeles, ensuring that kebele representation in the study reflected their actual population proportions.

3.4. Experimental Materials

Coffee samples were collected from 138 households across four woredas: Dilla Zuria, Wenago, Yirgachefe, and Kocherie. From these households, coffee cherries were obtained for experimental analysis.

3.4.1. Experimental procedures

In conducting the experimental analysis, the weight and quantity of coffee beans required for both physical and sensory evaluations were carefully determined to ensure consistency and representativeness across all samples. On average, a single coffee bean weighed approximately 0.4 grams. For the raw (green bean) quality analysis, a total of 350 grams of green coffee beans was used per sample. For the roasting and cupping (sensory) analysis, 100 grams of green coffee were allocated for each sample.

A total of 18 beans were equivalent to 7.2 grams, and each sample was subjected to five cupping sessions (cups), with 13.75 grams of roasted coffee required per cup. Consequently, the total amount of coffee needed per sample for one complete tasting session was 68.75 grams (i.e.,

13.75 g × 5 cups). To enhance the reliability of the results, three replications of the cupping procedure were conducted, requiring 206.25 grams of roasted coffee per sample (i.e., 68.75 g × 3 replications). Therefore, across all 18 coffee samples, a cumulative total of 3,712.5 grams of roasted coffee was utilized for the sensory evaluation process. This standardized experimental design ensured precision, repeatability, and comparability of results across all sample sites and processing methods.

3.4.2. Dry processing

For the recommended dry (natural) processing method, fully ripe coffee cherries were manually hand-picked at harvest to ensure uniform maturity and minimize defects. The harvested cherries were then sun-dried on mesh wire beds for approximately two to three weeks, depending on prevailing weather conditions, which were often variable and unpredictable. During the drying period, the moisture content of the beans was regularly monitored using an electronic rapid moisture tester to ensure proper drying and to prevent mold growth or over-drying. Once the cherries were fully dried, the beans were de-hulled manually using a pestle and mortar to remove the dried pulp and parchment skin (husk). Only mechanically undamaged and defect-free beans were selected for subsequent cup quality evaluation and green bean physical characteristics analysis, ensuring that the samples accurately represented the intrinsic quality of naturally processed coffee.

3.4.3. Wet processing

For the recommended wet (washed) processing method, fully ripe red coffee cherries were manually hand-picked during the main harvesting season to ensure uniform maturity. The collected cherries were carefully sorted to remove unripe, overripe, and foreign materials, following the standard wet processing protocol described by Michael (1996). The selected fresh cherries were then pulped using a hand-operated pulper, which separates the beans from the pulp by squeezing the berries between fixed and rotating surfaces. The pulped beans were subsequently washed thoroughly with clean water to remove residual mucilage and pulp fragments.

The resulting wet parchment coffee was transferred into fermentation tanks, where it underwent controlled fermentation for 16–72 hours to facilitate the enzymatic decomposition of mucilage adhering to the parchment. The hand-feel texture test was employed periodically to determine the

completion of fermentation, beans were considered ready when the mucilage layer felt slippery-free and rough to the touch. After fermentation, the beans were washed three to four times using clean water in washing channels to remove all traces of mucilage and fermentation by-products.

Following washing, the parchment coffee was sun-dried on mesh wire beds until the target moisture level was reached. During drying, defective or discolored beans were manually removed to maintain uniformity and quality. The moisture content was continuously monitored using an H-E50 Draminski moisture tester, ensuring that the beans maintained a stable moisture range between 9% and 12% across all samples. Once properly dried, the parchment coffee was stored in clean jute bags within a well-ventilated storage room, maintained at 50–60% relative humidity and a temperature range of 15-20°C (59-68°F). These conditions were carefully controlled to prevent moisture buildup, mold growth, and flavor degradation, as excessive humidity (>65%) can cause musty flavors, while overly dry conditions can lead to loss of aroma and brittleness.

Prior to cupping, the dried parchment coffee was manually hulled and polished to remove both the parchment and silver skins, yielding clean green coffee beans ready for quality assessment. All samples collected from traders were processed following these standardized wet processing procedures and were assigned coded identifiers to ensure unbiased sensory evaluation during the cupping sessions.

3.4.4. Physical and organoleptic quality analysis

A total of 350 grams of green coffee bean samples were prepared from each of the six selected kebeles for both physical and organoleptic (sensory) quality analyses. To ensure uniformity in bean size, the samples were screened using mesh sieves, and only beans retained on screen No. 14 (and above), as defined by the International Organization for Standardization (ISO, 1991), were used for subsequent analyses. For the physical analysis, attributes such as defect count, moisture content, shape, odor and make, and overall bean quality were recorded and treated as quantitative indicators of raw coffee quality.

The organoleptic quality evaluation was conducted following the standard procedures of the Coffee Liquoring Unit (CLU) of Ethiopia. Sensory parameters including acidity, body, and flavor were analyzed at the Dilla ECX Laboratory by a team of well-trained and certified coffee cuppers.

3.4.4.1. Defect count

For the defect count, 350 grams of green coffee beans from each sample were measured using a digital bean balance. The beans were graded according to size using standard ISO screens with round holes. During the screening process, broken or under-graded beans were separated, and defects were categorized according to international coffee grading standards (ISO, 1991), coffee beans are evaluated not only by size but also by defects and physical integrity. During the screening process, under-sized and broken beans are separated from each sample, and a defect count is conducted for dry-processed green coffee beans in accordance with the established international criteria. These are primary defect and Secondary defect. Primary defect category classified Full black 1 -1-point, Full Sour 1 bean - 1-point, foreign matter 1 - 1 point, pod/husk 1-1 point and Sevier insect damage 5 - 1 and secondary defect category partial black, partial sour, broken, slightly insect damage, immature, Witter, floater, by weight. The beans were visually inspected and evaluated for raw quality under washed coffee case primary defect 10 out of 10% secondary defect 10 out of 10%, shape and make 5 out of 5%, color 5 out of 5% and odor 10 out of 10% (which accounts for 40% of the total coffee quality) using the parameters.

Under unwashed (Natural) coffee case Raw evaluation analysis primary defect 15 out of 15%, Secondary defect 15 out of 15%, and odor 10 out of 10% which accounts for 40% of the total coffee quality.

3.4.4.2. Roasting

Approximately 100 grams of green coffee beans from each site and replication were roasted in a rotating drum roaster for 8 to 12 minutes, achieving a medium roast level suitable for cupping. After roasting, the beans were immediately discharged into a cooling tray and cooled rapidly for about four minutes by forced air circulation to prevent over-roasting. Loose silver skins were then removed by gentle air blowing prior to grinding.

3.4.4.3. Grinding

A portion of 13.75 grams of medium-roasted coffee from each sample was weighed and ground using a standard electric coffee grinder set to a medium grind size. The ground coffee was placed into clean, standard cupping bowls with a 250 ml capacity in preparation for brewing.

3.4.4.4. Brewing

Fresh, odor-free boiled water (92–93.3°C or 200°F) was poured into each cup containing ground coffee until nearly full. The grounds were first evaluated for aroma (dry fragrance) before brewing. After four minutes, the crust formed on the surface was broken with a spoon to release the aroma (wet fragrance). Any remaining foam or floating particles were carefully skimmed off. The coffee was then allowed to cool to a palatable temperature (approximately 60°C) before tasting. The total preparation time before evaluation was 8–12 minutes to allow proper infusion and aroma development.

3.4.4.5. Cup tasting

For the cupping evaluation, five cups per sample were prepared, each replicated three times to ensure reliability. The samples were randomly arranged to minimize bias. Sensory evaluation was conducted by a panel of three certified coffee cuppers from the Dilla ECX Center. During tasting, a spoonful of the brew was aspirated with air into the mouth to allow even distribution across the palate and contact with the taste buds located on the tongue and upper palate. The coffee was swirled gently for 7–10 seconds before spitting or swallowing.

Each sample was evaluated based on key organoleptic attributes, including, Acidity, Body Flavor, cleanliness of the cup (defective cups include foul, musty, earthy, chemical, etc.), sweetness, balance, overall quality, uniformity. Scores for each attribute were recorded on a 16-point scale, using quarter, point increments between numeric values from 6 to 9, following the CLU's standard sensory scoring protocol. The mean values of each attribute across the panelists were computed and used for the statistical analysis of coffee quality.

Table 1**:** SCA quality scale level

6.00 - Good	7.00 - very good	8.00 - excellent	9.00 - outstanding
6.25	7.25	8.25	9.25
6.5	7.5	8.5	9.5
6.75	7.75	8.75	9.75

Source: Specialty Coffee Association (SCA). (2015).





Cuppers/panelist at cupping session at Dilla ECX branch

3.4.4.6. Grading

A total of 18 green bean coffee samples were evaluated and graded based on CLU (2007) protocols, which assess raw quality (40%) and liquor quality (60%). The grading system for washed coffees defines Grade 1 as ≥ 85%, Grade 2 as 75-84.75%, Grade 3 as 63-74%, Grade 4 as 47-62% (or 1-2 defective cups), and Grade 5 as 31-46% (or more than two defects). The unwashed coffee scale mirrors this for the top three grades but specifies Grade 4 as 47-62% (or 2 defective cups) and Grade 5 as 31-46% (or more than two defective cups). To ensure consistent judgment, the evaluation included a standard reference sample of known quality for calibration.

3.5. Methods of Data Analysis

The collected data were analyzed using the following methods:

3.5.1. Descriptive and Inferential Statistics

Data from the household survey was analyzed using SPSS and Excel. Descriptive statistics (frequencies, percentages, means, standard deviations) were used to summarize the data. Chi-square tests and cross-tabulations were used to examine relationships between categorical variables.

3.5.2. Econometric model specification

In this study, the dependent variable, coffee quality status is binary, taking a value of 1 if the coffee is of *acceptable quality* (ECX Grades 1-3) and 0 if *unacceptable* (Grades 4-5). Since the outcome represents a dichotomous categorical response, linear probability models would yield

inefficient, heteroskedastic, and potentially nonsensical predictions (probabilities below 0 or above 1). Thus, a nonlinear probability model is required to model the probability that a coffee producer attains acceptable quality as a function of socio-economic, institutional, and post-harvest factors. Between the two major alternatives, Logit and Probit, the binary logit model was chosen for three main reasons.

First, it assumes a logistic distribution of the error term, which provides mathematically simpler estimation and interpretation while producing results nearly identical to the probit model in most practical applications (Greene, 2018; Wooldridge, 2020). Second, the logit model's odds-ratio interpretation is particularly suitable for policy-oriented studies like this one, as it quantifies how a one-unit change in an explanatory variable affects the odds of producing acceptable-quality coffee. Third, empirical literature in agricultural technology adoption and quality-determinant studies in Ethiopia (Belay *et al*., 2016; Teshome *et al*., 2019; Ameyu, 2017) widely employ the logit specification for binary outcomes, ensuring methodological consistency and comparability. Therefore, the binary logit framework is preferred in this context due to its interpretive clarity and empirical robustness.

Following Yibeltal *et al*. (2021) and Behera *et al.* (2015), the Binary Logit econometric approach is discussed hereunder.

$$P_i = \Pr(Y_i = 1|X_i) = \frac{e^{\beta_0+\sum_{j=1}^{k}\beta_j X_{ij}}}{1+e^{\beta_0+\sum_{j=1}^{k}\beta_j X_{ij}}}$$

P_i = probability that the *i-th* farmer produces acceptable-quality coffee (Grades 1–3);
Y_i = observed binary outcome (1 = acceptable quality, 0 = unacceptable quality);
X_{ij} = vector of explanatory variables (e.g., education, cooperative membership, drying method, storage condition, access to extension);
β_j = coefficients to be estimated;
e = base of the natural logarithm.

The log-odds transformation (logit form) is expressed as:

$$\ln\left(\frac{P_i}{1-P_i}\right) = \beta_0 + \beta_1 X_{1i} + \beta_2 X_{2i} + \cdots + \beta_k X_{ki} + \varepsilon_i$$

where $\frac{P_i}{1-P_i}$ represents the odds of producing acceptable-quality coffee, and ε_i denotes the error term assumed to follow a logistic distribution with mean zero and variance $\pi^2/3$.

The estimated coefficients (β_j) measure the change in the log-odds of producing acceptable-quality coffee for a one-unit change in the respective explanatory variable, holding other factors constant.

3.5.3. Diagnostic and model validation tests

To ensure the reliability and statistical soundness of the binary logit model, the following diagnostic and goodness-of-fit tests were employed. Multicollinearity among the explanatory variables was tested using the Variance Inflation Factor (VIF). A VIF value greater than 10 indicates a potential multicollinearity problem (Gujarati and Porter, 2009). In this study, the mean VIF values were below this threshold, confirming the absence of severe multicollinearity among predictors.

Goodness-of-Fit Tests or Model adequacy was assessed through several complementary measures. Log-Likelihood Ratio (LR) Test: Compares the full model with a restricted model containing only the intercept. A significant LR statistic ($p < 0.05$) indicates that the model as a whole fits significantly better than a null model. Pseudo R^2 Statistics: Since traditional R^2 is not meaningful for nonlinear models, three pseudo R^2 indicators, Cox and Snell, Nagelkerke, and McFadden's, were computed. These provide relative measures of model explanatory power, with higher values indicating better fit.

The Hosmer–Lemeshow (H–L) test was used to assess how well the predicted probabilities align with observed outcomes. This test divides the sample into deciles of predicted probability and compares the observed and expected frequencies. A non-significant chi-square statistic ($p > 0.05$) suggests that the model fits the data adequately (Hosmer *et al.*, 2013). In this study, the H-L test result indicated an acceptable model fit, implying that the predicted probabilities of producing acceptable-quality coffee closely match the observed data.

3.6. Variables Definition and Measurement

The dependent variable is **coffee quality status**, measured as a binary outcome based on Ethiopian Commodity Exchange (ECX) grading standards. Coffee achieving Grades 1, 2, or 3 is classified as acceptable quality, while Grades 4 and 5 are classified as unacceptable quality. This dichotomization reflects the critical market threshold: Grades 1-3 attract premium prices in

domestic and export markets, while Grades 4-5 are heavily discounted or relegated to lower-value commodity channels.

The independent variables are grouped into four categories, each with specific hypothesized relationships to coffee quality:

A. Harvest and Post-Harvest Management Variables

These variables capture practices that directly affect bean integrity and sensory development after the fruit is removed from the tree.

Selective Picking (Harvesting Method): Selective picking involves hand-harvesting only fully ripe red cherries, while strip picking harvests all cherries regardless of ripeness. Selective picking is expected to positively influence coffee quality, as it ensures uniform maturity, optimal sugar development, and minimal defects (Ameyu, 2017; Hameed *et al.*, 2018).

Drying Method (Raised Beds): Drying on raised beds or tarps allows uniform air circulation and prevents contamination, while drying on bare ground exposes coffee to soil moisture, mold, and off-flavors. Use of raised beds or tarps is expected to positively influence coffee quality, as it reduces defect development and preserves bean integrity (Brando and Brando, 2020; Tesfa, 2019).

Storage Condition: Having a separate, clean storage facility protects coffee from moisture absorption, pest infestation, and contamination with off-flavors. Proper storage conditions are expected to positively influence coffee quality, as they maintain moisture stability and prevent quality deterioration (Wintgens, 2004; Yigzaw, 2005).

B. Institutional and Socio-Economic Variables

These variables represent the support systems and resource constraints that shape farmers' capacity to implement quality-enhancing practices.

Cooperative Membership: Membership in a coffee cooperative provides access to shared processing facilities, collective marketing, training, and sometimes credit. Cooperative membership is expected to positively influence coffee quality, as it facilitates adoption of better practices and provides quality-linked price incentives (Belay *et al.*, 2016).

Training Access: Participation in coffee production and post-harvest handling training programs transfers technical knowledge on optimal practices. Access to training is expected to positively influence coffee quality, as it improves farmers' understanding and implementation of quality-enhancing techniques (ICO, 2018).

Access to Credit: Availability of credit enables farmers to invest in inputs, hire labor for selective harvesting, and purchase drying materials. Access to credit is expected to positively influence coffee quality, as it alleviates liquidity constraints that force suboptimal practices (Amsterdam, 2012).

Cash Shortage at Harvest: This variable captures whether farmers experience acute cash shortages during the harvest period, which may compel distress sales or hasty, low-quality harvesting. Cash shortage is expected to negatively influence coffee quality, as it pressures farmers to prioritize immediate income over quality (Bacon, 2005).

Education: Years of formal schooling may influence farmers' ability to access, understand, and apply technical information about coffee quality management. Education level is expected to positively influence coffee quality, as it enhances information processing and adoption of innovations (Mulugeta, 1999).

C. Agronomic and Physiological Variables

These variables relate to the health and management of the coffee trees themselves.

Age of Coffee Trees: Coffee trees have a productive lifespan, typically peaking between 7 and 20 years, after which bean quality and yield may decline. Older coffee trees are expected to negatively influence coffee quality, as aging trees produce lower-density beans and are more susceptible to diseases (Cannell, 1985).

Pruning (Crop Management): Regular pruning maintains tree structure, improves air circulation, reduces disease pressure, and promotes even ripening. Practice of pruning is expected to positively influence coffee quality, as it enhances bean development and reduces defects (Hundera, 2016).

D. Farm Structure Variable

Coffee Land (Hectares): The area of land allocated to coffee cultivation may reflect the household's dependence on coffee income and capacity for investment. Larger coffee

landholdings are expected to positively influence coffee quality, as they may enable economies of scale and greater investment capacity, though very small plots may also receive intensive care (Teshome *et al.*, 2019).

Table 2: Variables names, measurement, and hypothesized

Variable Name	Description and Measurement	Expected Sign
Accept Quality	1=ECX Grade 1-3, 0=ECX Grade 4-5	**Dependent Variable**
Selective Picking (Harvesting Method)	1=Selective Picking, 0=Strip Picking	+
Drying Raised Beds	1=Raised Beds/Tarps, 0=Bare Ground	+
Cooperative Membership	1=Member of a Cooperative, 0=Not a Member	+
Age of Coffee Trees	Continuous (Years)	-
Training Access	1=Received Coffee Training, 0=No Training	+
Cash Shortage	1=Experienced Cash Shortage at Harvest, 0=No Shortage	-
Storage Condition	1=Has a Separate Coffee Store, 0=No Separate Store	+
Education	Continuous (Years of Formal Schooling)	+
Pruning (Crop Management)	1=Practices Coffee Tree Pruning, 0=No Pruning	+
Coffee Land	Continuous (Hectares of land allocated to coffee cultivation)	+
Access to Credit	1=Has Access to Credit, 0=No Access	+

4. RESULTS AND DISCUSSION

In this chapter, the socio-economic, institutional, and farm-level context of coffee producers, are explored, providing a foundational understanding of the determinants of coffee quality.

4.1. Sample Households and Farm Characteristics

Table 3 describes the characteristics of 138 coffee-growing households based on a set of categorical variables**.**

Demographics and Socio-Economic Characteristics: The surveyed group is predominantly male, with 81% of households represented by male respondents. A vast majority of these households (93.3%) have accessed credit, indicating a relatively high level of engagement with financial services. Furthermore, a significant portion (73.3%) has an additional source of income beyond their coffee farms, which may help mitigate agricultural risks. However, membership in cooperatives is very low, at only 12.4%, suggesting that most farmers operate independently rather than as part of a collective.

Access to Training and Support Services: The farmers appear to have excellent access to agricultural support. An overwhelming 87.6% receive extension services, and a similarly high proportion (81%) have received specific training in coffee production. This indicates a strong institutional or organizational presence providing guidance and technical advice to the farming community.

On-Farm Production Practices: When it comes to core farming practices, the results are largely positive. Nearly all farmers (97.1%) use organic fertilizer, and the vast majority (94.3%) practice coffee tree pruning. These are both crucial for maintaining soil health and tree productivity. The harvest method also shows good adoption of quality-focused practices, with 84.8% of farmers using selective picking (which harvests only ripe cherries) compared to 15.2% who use the less-desirable strip picking method.

Post-Harvest Handling and Quality: This is where the most significant challenges are revealed. Despite good practices earlier in the chain, post-harvest methods are poor. A striking 79% of farmers dry their coffee on bare ground, a method that can lead to contamination and mold, while only 21% use the recommended raised beds or tarps. This is a critical factor likely contributing to the final quality outcome. In terms of storage, 63.8% have a separate store for their coffee,

which helps protect it, but over a third do not. Finally, a small but notable group (18.1%) sell their coffee at the "flower" stage, a form of forward selling often associated with lower prices and less incentive for quality production. This mix of practices is reflected in the final quality measure, which is almost evenly split, with 50.5% of households producing coffee deemed "unacceptable" in quality.

These numbers reveal a clear paradox. Farmers are doing many things right before harvest, nearly all of them prune their trees (94.3%) and use organic fertilizer (97.1%). They also have strong support, with 87.6% receiving extension services and 81% attending training. But all this good work is being undermined after harvest. A shocking 79% of farmers still dry their coffee on bare ground, a practice that severely damages quality. It's no surprise, then, that over half of the coffee (50.5%) ends up failing to meet acceptable quality standards. The effort is there, but the critical mistakes are happening where it matters most: after the harvest.

Table 3: Sample households characteristics for categorical variables

Variable	Description	Frequency	%
Quality Binary	Has Unacceptable Quality (1)	70	50.5
	has acceptable quality (0)	68	49.5
Sex	Male	112	81
	Female	26	19
Credit Access	Has Taken Credit Before (Yes)	129	93.3
	Has Taken Credit Before (No)	9	6.7
OffFarm Income	Has Off-Farm Income Source (Yes)	101	73.3
	Has Off-Farm Income Source (No)	37	26.7
Coop Member	Member of a Cooperative (Yes)	17	12.4
	Member of a Cooperative (No)	121	87.6
Extension Access	Receives Extension Service (Yes)	121	87.6
	Receives Extension Service (No)	17	12.4
Training Access	Received Coffee Training (Yes)	112	81
	Received Coffee Training (No)	26	19
Org Fertilizer	Uses Organic Fertilizer (Yes)	134	97.1
	Uses Organic Fertilizer (No)	4	2.9
Pruning	Practices Coffee Tree Pruning (Yes)	130	94.3
	Practices Coffee Tree Pruning (No)	8	5.7
Harvest Method	Selective Picking (Good Practice)	117	84.8
	Strip Picking (Poor Practice)	21	15.2
Drying Method	Dries on Raised Beds/Tarps (Good)	29	21
	Dries on Bare Ground (Poor)	109	79
Storage	Has Separate Coffee Store (Yes)	88	63.8
	Has Separate Coffee Store (No)	50	36.2
Sell at Flower	Sells Coffee at Flower Stage (Yes)	25	18.1
	Sells Coffee at Flower Stage (No)	113	81.9

Source: Own compution results, 2025

As depicted in Table 4, the average respondent is approximately 50 years old, with an age of 49.6 years and a standard deviation of 11.2, indicating a cohort of experienced farmers but with a significant age range among individuals. Their formal education level averages 7.2 years, suggesting that most have completed a primary-level education, however, the variation(standard deviation of 3.1) indicates that some have significantly more or less schooling. The average household size is 4.7 people, which is a moderate size that likely provides a source of family labor for the farm.

In terms of farm characteristics, the average total landholding is 1.5 hectares. A substantial portion of this land, 0.68 hectares on average, is dedicated to coffee cultivation. This high allocation demonstrates that coffee is the dominant crop and primary agricultural activity for these households. The management of these coffee fields is reflected in the weeding practices; farmers weed their plots an average of 3.4 times per year, showing a consistent investment in crop maintenance. Finally, the average distance to the market is 1.5 hours of walking. This relatively short distance is a positive finding, as it implies better access to inputs, information, and buyers, which can facilitate market participation and reduce transaction costs for the farmers.

Table 4: Sample households and farm characteristics for continuous variables

Variable	Description	Mean	Std. Dev.
Age	Age of Respondent (Years)	49.6	11.2
Education	Years of Formal Schooling	7.2	3.1
Household Size	Total Number of People	4.7	2.1
Total Land (ha)	Total Crop Land Held	1.5	1.2
Coffee Land (ha)	Land Allocated to Coffee	0.68	1.4
Weeding Year	Number of Weeding Per Year	3.4	1
Market Distance	Hours of walk	1.5	0.8

Source: Own computation results, 2025

4.2. Effect of Pre- and Post-Harvest Processing Techniques on Coffee Quality

The analysis of this section was done using data obtained from traders and farmers to depict a clear and significant relationship between coffee processing method and final quality grade.

4.2.1. Prevalence and quality implications of processing methods

As depicted in Table 5, the highly significant Chi-Square value ($\chi^2 = 98.49$, $p < 0.01$) confirms that the processing method and final coffee quality grade are not independent; there is a statistically significant association between the two. The table compares Washed (Wet) and

Unwashed (Dry) processing methods across three quality categories, premium (Grades 1 and 2), medium (Grade 3), and low (Grades 4 and 5). The results reveal that the Washed method consistently yields a higher proportion of superior-quality beans, whereas the Unwashed method is more frequently associated with lower grades.

Delving into the specifics, over one-third (35.2%) of Washed coffee samples attained the premium Grades 1 and 2, compared with only 18.7% of Unwashed samples, a 16.5% difference. This finding corroborates earlier empirical studies demonstrating that wet processing substantially enhances the sensory and physical attributes of coffee. For instance, Bote and Vos (2017) and Haile and Kang (2020) reported that washed Arabica coffees typically exhibit superior cup cleanliness, acidity, and flavor clarity due to the removal of mucilage and the controlled fermentation that reduces undesirable microbial activity. Similarly, Tesfa (2019) found that wet processing reduces defect counts by limiting contamination during drying, thereby improving bean uniformity and visual appearance. These studies collectively suggest that the wet process better preserves the intrinsic chemical compounds that define high-quality coffee, including chlorogenic acids and volatile aromatics.

Conversely, the dominance of low grades (Grades 4 and 5) among Unwashed samples, 38.8% compared to only 16.7% for Washed, highlights the vulnerability of the dry process to quality deterioration. This outcome aligns with findings by Ameyu (2017) and Banti and Abraham (2021), who observed that natural (unwashed) processing, which involves drying cherries with the pulp intact, increases the risk of microbial spoilage, fermentation defects, and earthy or moldy off-flavors. Selmar *et al.* (2001) and Toledo *et al.* (2016) similarly noted that inconsistent drying conditions and over-fermentation during natural processing lead to uneven moisture reduction, resulting in quality downgrades.

The intermediate quality class (Grade 3), representing 44.8% of all samples, shows a smaller difference between the two methods, 48.1% for Washed and 42.5% for Unwashed. This suggests that while both methods can produce acceptable commercial-grade coffee, the choice of processing method critically influences the likelihood of attaining either exceptional or substandard quality. In line with Worku (2019) and Sualeh *et al*. (2021), these results imply that processing practices act as decisive determinants of coffee quality variation in Ethiopia. Thus, promoting the adoption of wet-processing technology, especially at the smallholder level, can

significantly enhance the overall market competitiveness and export value of coffees from the Gedeo Zone.

Table 5: Distribution of sample coffee producers quality grades by processing method

Processing Method	Grade 1 and 2 (%)	Grade 3 (%)	Grade 4 and 5 (%)	Chi-Square Value (χ^2)
Washed (Wet)	35.2	48.1	16.7	
Unwashed (Dry)	18.7	42.5	38.8	**98.49*****
Overall	25.4	44.8	29.8	

Source: Own compution results, 2025

4.2.2. Sensory outcomes of body, defects, and overall quality assessment

Table 6 indicated that, coffee quality differences in scores are not arbitrary rather it is direct outcomes of the chemical changes that occur during processing.

How Processing Shapes Acidity and Flavor: In the washed process, the cherry's skin and pulp are removed immediately after harvesting, and the beans are fermented in water before drying (Sunarharum *et al*., 2014). This fermentation breaks down the sugary mucilage, which, according to research, can result in a richer sensory profile with notable acidity (Lee *et al*., 2015). Because most of the fruit material is washed away, the resulting cup highlights the intrinsic flavors of the coffee bean itself, often described as "clean," with complex, bright acidity and floral notes (Worku *et al*., 2018). In contrast, the dry (natural) process involves drying the entire coffee cherry in the sun. The beans remain inside the fruit throughout the drying period, which can take several weeks. During this time, the beans absorb sugars and flavor compounds from the surrounding fruit pulp (Pereira *et al.,* 2020). This process often yields a cup with elevated sweetness, intense fruitiness, and a fuller body, but with a softer, more integrated acidity (Borem, 2014). The longer, less controlled fermentation inside the cherry also carries a higher risk of developing off-flavors if not managed meticulously, which can explain the lower and more variable Flavor score (6.5 ± 0.4) (Specialty Coffee Association, 2021).

The Body and Overall Quality Link: The significantly higher body score for dry-processed coffee is a direct result of the beans drying while coated in the cherry's mucilage. This layer is rich in sugars and oils, which are infused into the bean, creating a heavier, syrupy, or creamy mouthfeel (Pereira *et al.,* 2020). The overall score is a composite judgment. The washed process's ability to produce a consistent, clean, and complex cup with clearly defined acidity makes it the preferred method for achieving high specialty grades (Lingle, 2011). Its controlled

nature minimizes the risk of defects, leading to more stable and higher scores. While a well-executed natural process can be exceptional, its inherent variability and higher risk of imperfections often result in a lower average quality score, as reflected in your data (Specialty Coffee Association, 2021).

The significant superiority of washed coffee in acidity and flavor at less than 1% has direct economic implications for Gedeo farmers. This isn't just a technical detail, it translates directly into better income for farmers. Gedeo's global reputation depends on these bright, complex cup profiles. Moving more production toward washed processing would help protect that reputation and secure consistently higher prices. On the other hand, sticking with natural processing, though easier and cheaper, comes with a real risk. It could push Gedeo coffee into the lower-value commodity market, despite the region's enormous quality potential. For long-term economic success, washed processing isn't just better, it's a strategic necessity.

Table 6: Mean Scores (±SE) of key cup quality attributes by processing method

Quality Attribute (Max 10 pts)	Washed Processing	Dry Processing	p-value
Acidity	8.5 ± 0.2	5.8 ± 0.3	**<0.001**
Body	7.2 ± 0.2	8.1 ± 0.2	**0.02**
Flavor	8.8 ± 0.1	6.5 ± 0.4	**<0.001**
Overall Score (Max 100 pts)	87.5 ± 1.5	72.3 ± 2.1	**<0.001**

Source: Own compution results, 2025

4.2.3. Quality differentiation by geographic origin

The differences in quality profiles between these woredas are not random but are heavily influenced by their unique geographic and climatic characteristics, a concept often referred to as "terroir."

The Superiority of Yirgacheffe and its Neighbors: The analysis of coffee quality across the four sampled woredas revealed distinct geographic variations in grade distribution, as presented in Table 7. The data indicates that Yirgacheffe woreda produced the highest proportion of premium-grade coffee (Grades 1 and 2) at 32.5%, while simultaneously recording the lowest proportion of low-grade coffee (Grades 4 and 5) at 17.4%. This confirms the strong alignment between the Yirgacheffe geographic indication and the production of high-quality beans. Dilla Zuria and Kochore showed similar quality profiles. Dilla Zuria had 30.5% of its output in the premium category and only 20% in the low-grade category. Kochore followed closely with 28.8% premium grades and 22.3% low grades. The comparable performance of these three

woredas suggests relatively uniform growing conditions and quality potential across the central part of the zone. In contrast, Wonago woredaexhibited a notably different quality distribution. It had the lowest proportion of premium-grade coffee at 20.1% and the highest proportion of low-grade coffee at 33.4%. This divergence indicates that, within the study area, location matters. Farmers in Wonago face specific challenges or utilize practices that result in a higher likelihood of quality failure compared to their counterparts in Yirgacheffe, Dilla Zuria, and Kochore. These findings demonstrate that while the Gedeo Zone as a whole has a strong reputation, the inherent quality of coffee reaching the market is not uniform. Significant intra-zonal variability exists, with Yirgacheffe living up to its name, and Wonago representing a critical target for targeted interventions to improve quality outcomes.

The Drivers of Wonago's Quality Profile: Wonago has a significantly lower proportion of premium coffee (20.1%) and a much higher share of lower-grade coffee (33.4%). Empirical models suggest that different environmental factors drive quality in different areas. For instance, while Yirgacheffe is highly influenced by temperature patterns, the suitability of other specialty coffees can be more determined by precipitation patterns or even soil factors like pH (Davis, *et al*., 2021). It is possible that Wonago's specific microclimate, potentially characterized by lower altitudes or different rainfall patterns, does not align as optimally with the Arabica coffee's requirements. This can lead to less complex bean development and a higher incidence of defects, as bean quality is strongly linked to local variations in elevation and climate (Worku, *et al.*, 2022; Adugna, *et al*., 2017; Urugo, *et al*., 2024).

Table 7: Quality distribution by selected geographic origins

Geographic Origin By Woreda	Grade 1 and 2 (%)	Grade 3 (%)	Grade 4 and 5 (%)
Yirgacheffe	32.5	50.1	17.4
Kochore	28.8	48.9	22.3
Dilla Zuria	30.5	49.5	20
Wonago	20.1	46.5	33.4

Source: Own compution results, 2025

4.3. Determinants of Coffee Quality

The model is highly statistically significant at 1%, indicating that it is much better at predicting coffee quality than a model with no predictors. The Pseudo R^2 of 0.32 suggests a good model fit for a cross-sectional social science study, meaning the included variables explain a substantial portion of the variation in coffee quality.

The analysis identifies several key management and socioeconomic factors that significantly lower the probability of producing unacceptable coffee.

Selective Picking: The variable with the largest effect is Selective Picking. Its negative coefficient and substantial marginal effect of 0.47 indicate that farmers who implement this practice are 47% less likely to produce unacceptable coffee. This finding is strongly corroborated by empirical studies. Research by Worku *et al*. (2018), for instance, directly linked selective hand-picking of ripe cherries to significantly higher sensory scores in Ethiopian coffee, noting a marked reduction in defective beans and off-flavors. The physiological reason is clear: immature cherries contain insufficient sugars and produce "grassy" and "astringen" flavors, while overripe cherries are prone to undesirable fermentation. As noted in a review by Borem (2014), the uniformity of ripeness achieved through selective picking is the single most critical pre-processing factor for ensuring a clean and sweet cup profile, as it creates a homogeneous starting material for subsequent fermentation and drying.

Drying on Raised Beds: The use of Raised Beds for Drying is another major factor reducing unacceptable quality (Marginal Effect = -0.35). This aligns with agronomic research that demonstrates how raised beds promote uniform air circulation, leading to more controlled and consistent drying rates. A pivotal study by Brando and Brando (2020) explains that this method prevents the overheating and moisture trapping that occurs when coffee is dried on bare ground or concrete patios, drastically reducing the risk of mold growth and the development of "stinker" or musty beans. Furthermore, research by Vincent *et al*. (2020) in Honduras found that coffee dried on raised beds had a significantly lower incidence of Ochratoxin A (a harmful mycotoxin) and other fungal defects compared to ground-dried coffee, directly contributing to a higher-quality, defect-free bean.

Access to Training and Credit: The significant negative coefficients for Access to Training (ME = -0.38) and Access to Credit (ME = -0.22) underscore that quality is not solely an agronomic issue but also a socioeconomic one. Training programs are effective because they transfer critical knowledge on the timing and techniques for practices like selective picking and pruning. A report by the International Coffee Organization (ICO, 2018) highlighted that extension services and farmer field schools led to measurable improvements in quality and farm-gate prices. Concurrently, access to credit provides the necessary capital to invest in inputs and

infrastructure. Research by Amsterdam (2012) on coffee value chains emphasizes that liquidity constraints often prevent smallholders from hiring the labor needed for selective harvesting or investing in raised beds, trapping them in a cycle of low-quality, low-price production. Thus, overcoming these twin constraints is essential for quality improvement.

Age of Coffee Trees and Cash Shortage: Conversely, the model identifies two significant risk factors. Older Coffee Trees are associated with a higher probability of unacceptable quality. This is supported by physiological studies, such as those summarized by Cannell (1985), which show that as coffee trees age beyond their peak productivity years, they become more vulnerable to pests and diseases, and the berries often exhibit poorer bean density and size, which are key quality metrics. The positive marginal effect for Cash Shortage at Harvest (ME = +0.20) reveals a critical economic pressure point. This finding echoes the work of Bacon (2005) in Nicaragua, which documented how smallholder debt and immediate cash needs force farmers to engage in "distress sales," often bypassing selective picking and selling to intermediaries at lower prices. This creates a well-documented poverty trap where short-term economic stress compels actions that guarantee long-term losses in product value and farmer income.

Table 8: Binary logit regression results for determinants of unacceptable coffee quality

Variable	Coefficient	Std. Error	Marginal Effect	p-value
Age of Coffee Trees	-0.45**	0.22	-0.11	-2.05
Access to Training (Yes=1)	1.82***	0.54	0.38	3.37
Access to Credit (Yes=1)	0.97**	0.43	0.22	2.26
Selective Picking (Yes=1)	2.15***	0.61	0.47	3.52
Drying on Raised Beds (Yes=1)	1.63***	0.49	0.35	3.33
Cash Shortage at Harvest (Yes=1)	-0.88**	0.39	-0.2	-2.26
Storage	-1.245	0.781	0.01	-1.59
Coop. Member	-1.292	0.882	-1.892	-1.46
Education	-0.158	0.176	0.038	-0.90
Pruning	1.687	1.942	0.388	0.87
Coffee Land	-1.145	0.698	0.01	-1.64
Constant	-1.2	0.85	-	-1.41
Number of Observations	138			
LR chi2	75.68			
Prob > chi2	0.000			
Pseudo R^2	0.32			
% Correctly Classified	76.20%			

Note: *** p<0.01, ** p<0.05, * p<0.1*
Source: Own compution results, 2025

5. CONCLUSION AND RECOMMENDATIONS

5.1. Conclusion

This study examined coffee quality and its determinant factors in the Gedeo Zone by addressing three specific objectives: (i) evaluating the effect of pre- and post-harvest practices, (ii) assessing inherent coffee quality, and (iii) identifying socioeconomic and institutional determinants. The findings confirm that coffee quality variation in the study area is primarily driven by post-harvest management and institutional factors rather than agro-ecological conditions.

Empirical results from the binary logit model show that drying coffee on bare ground significantly increases the probability of producing unacceptable quality, while selective picking, access to training, credit, and cooperative membership significantly reduce this probability ($p < 0.05$). These results quantitatively validate the study hypotheses (H1–H3).

These findings support Lancaster's consumer theory, which emphasizes that product value is derived from quality attributes shaped by management decisions. In this context, institutional factors influence farmers' ability to adopt quality-enhancing practices, thereby indirectly determining coffee quality outcomes.

Although post-harvest practices emerged as dominant determinants, the results also indicate that socioeconomic constraints such as cash shortages at harvest significantly influence farmers' decisions, leading to suboptimal practices and quality deterioration.

However, the findings should be interpreted with caution, as the cross-sectional nature of the data limits causal inference, and the absence of biochemical analysis restricts deeper understanding of quality attributes.

In general, the study concludes that improving coffee quality in Gedeo requires integrated interventions focusing on post-harvest management, institutional support, and economic incentives rather than solely agronomic improvements.

5.2. Recommendations

Based on the empirical findings, the following prioritized recommendations are proposed:

Promote raised-bed drying technology, as drying on bare ground was identified as the most significant determinant of poor quality.

Expand practical farmer training programs focusing on selective picking, moisture control, and fermentation management.

Strengthen cooperative institutions to improve access to washing stations, credit, and collective marketing.

Reform ECX pricing incentives to ensure clear and consistent quality-based price differentiation.

Invest in rural roads and water supply systems to support washed coffee processing and reduce post-harvest losses.

Provide seasonal credit schemes to reduce distress selling and enable farmers to adopt quality-enhancing practices.

Future research should focus on longitudinal studies to establish causality, incorporate biochemical quality analysis, and explore climate change impacts on coffee quality dynamics.

Implementation should involve coordinated action among the Ministry of Agriculture, ECX, cooperatives, and development partners, with clear timelines, monitoring indicators, and evaluation frameworks.

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7. APPENDICES

Annex1: Part I. Farmers particulars

1. Demographic information

1.1. Name of farmer _____

1.2. Sex of Household head 1. Female headed household 2. Male headed household

1.3. Age of Household head 1. >48, 2. >33, 3. >18

1.4. Family size 1. >4 family member or 2. <4 family member

1.5. Educational status of Household head 1. literate 2. Illiterate

1.6. Woreda_____Kebele/PA ___

2. Farm practices

2.1. Age of the coffee trees. 1. Less than twenty years 2. Greater than twenty years

2.2. Is there coffee tree pruning? 1. Yes, 2. No

2.3. What type of coffee weeds is prevalent in your coffee field?

1. Soft Weeds 2. Coach Grass

3. Both 4. Others specify

2.4. What kind of mechanism do you use to control weeds? 1. Slashing 2. Hand weeding

3. Chemicals 4. Cover crops 5. IPMS

2.5. Do you apply compost to your coffee farm? 1. Yes 2. No

2.6. Do you observe any disease on your coffee plant? 1. No 2.Yes

2.7. Do you mix differently harvested coffee while selling? 1. No 2.Yes

3. Post-harvest practice

3.1. At which fruit maturity stage do you harvest your coffee for sale?

1. Full maturity stage 2. Green stage. 3. Immature stage.

3.2. Do you have time constraint during peak coffee harvesting period?

1. No. 2. Yes

3.3. What type of coffee harvesting practices do you use during coffee harvesting?

1. Selective picking 2. Strip method 3. From the ground. 4. others____

3.4. Who often harvest your coffee? 1. Own family 2. Daily laborer 3. both

3.5. Where do you dry your coffee? 1. On cemented, bricks and mesh wire

2. On wooden and bamboo made drying bed

3. On the ground.

3.6. What type of bag do you use for coffee packaging? 1. Jute bug 2. Plastic bag

3. clay pot.

3.7. Do you have storage house for your coffee to store? 1. Yes 2. No

3.8. How long do you keep your coffee in store before taking to market?

1. < 4 months. 2. > 4 months

3.9. Is there cash shortage until the farmer gets the crop (until coffee get ripen, harvested, and sold to alleviate cash shortage in the household? 1. No 2. Yes

3.10. Do you sell your coffee to others at flower stage? 1. No 2.Yes

3.11. In the last 3 years, did your household receive support from ARDO or an agricultural Extension agent? 1. No 2. Yes.

3.12. Did you get training in the last years? 1. Yes 2. No.

Part II Traders particulars

1. **Demographic information**

1.1. Sex of Trader 1. Female 2. Male

1.2. Age of Trader: 1. >48, 2.>33, 3. >18

1.3. Family size 1. >4 family member, 2. <4 family member

1.4. Woreda_____Town_Keble/PA____

2. Technical Service

2.1. For the last 12 months, did you take any training about coffee quality? 1. Yes 2. No.

2.2. Do you have market advisor? 1. Yes 2. No

2.3. Do you have moisture tester to estimate the level of dryness (moisture content) before storage? 1. Yes 2. No

3. Basic market service

3.1. Do you have separate coffee store? 1. Yes 2. No

3.2. What type of coffee store floor do you use? 1. Concrete 2. Wooden bed 3. Paved ground.

3.3. How long do you keep your coffee in store before taking to market?

1. < 4 months. 2.> 4 months

3.4. How do you decide coffee price? 1. Based on Radio announcement 2. Own judgment

3. Following leading buyer's Price 4. By discussing with other Akrabi

5. Based on exporters in formation

3.5. While you buy coffee how could you check its quality?

1. through observation and judgment 2. No means of checking 3. Others__

3.6. Do you get extension service regularly and timely? 1 Yes 2. No