ASSESSMENT OF PRODUCTION AND MARKETING STATUS OF BANANA (*Musa spp.) AND IMPROVING* POSTHARVEST MANAGEMENT PRACTICES FOR SHELF LIFE AND QUALITY

Ph.D Dissertation

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ASSESSMENT OF PRODUCTION AND MARKETING STATUS OF BANANA (*Musa spp.) AND IMPROVING* POSTHARVEST MANAGEMENT PRACTICES FOR SHELF LIFE AND QUALITY

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By

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RECOMMENDATION SHEET

School of Graduate Studies

Jimma University

College of Agriculture and Veterinary Medicine

We hereby certify that we have read and evaluated this dissertation prepared under our supervision and recommend it to be accepted for defense.

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As Board of Examiners (BOE) of the Final PhD Open Defense, we certify that we have read and evaluated the dissertation prepared by Zenebe Woldu Adane, entitled: **"ASSESSMENT OF PRODUCTION AND MARKETING STATUS OF BANANA (*Musa spp.) AND IMPROVING* POSTHARVEST MANAGEMENT PRACTICES FOR SHELF LIFE AND QUALITY"**, and recommend it to be accepted; so as to enable him fulfill the requirements for Doctor of Philosophy (PhD) in Horticulture.

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Final approval and acceptance of the thesis is contingent upon the submission of the final copy to the Council of Graduate Studies (CGS) through the Graduate Committee (DGC) of the candidate's major Department.

DEDICATION

Dedicated to my late beloved grandmother, W/o Nigisty Tedla Desta, in memory of all the Godly things she had done and treasured into my being.

STATEMENT OF THE AUTHOR

First, I declare that this dissertation is my authentic work and that all sources of the materials used for this dissertation have been duly acknowledged. This dissertation has been submitted in partial fulfillment of the requirements for my PhD degree at Jimma University and is deposited at the University Library to be made available to borrowers under the rules of the Library. I also genuinely declare that this dissertation is not submitted to any other institution anywhere for the award of any academic degree, diploma, or certificate.

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BIOGRAPHICAL SKETCH

The author was born in Bora-Silawa Wereda of the then Raya-Azebo Awraja, now part of the Alaje Wereda of the Southern Zone of the Tigray Regional State, Ethiopia. He attended his primary schooling in the stated Wereda and partly at the 'Meserete' Elementary School in Mekelle town. Subsequently, he did his junior and high school education at Atse Yohannes Comprehensive High School in Mekelle town. He then joined the then Alemaya College of Agriculture under Addis Ababa University (now Haramaya University) and graduated with B.Sc. degree in Plant Sciences in 1983. He was then directly employed by the Institute of Agricultural Research (IAR) and served for 11 years at Jimma Agricultural Research Center (JARC) in various capacities, including as a National Team Leader of the Herbs and Spices Research. He did his post graduate study in Postharvest Technology (Crop Market Technology Option) and received his M.Sc. degree in 1993 from Silsoe College, Cranfield University of Technology, U.K. He then served for six years for Mekelle Agricultural Research Center (MARC) as a Head of the Horticulture Research Department, five years for the Institute of Biodiversity Conservation (IBC) as a Head of the Department of Horticultural Genetic Resources, three years for the Ethiopian Horticulture Development Agency (EHDA) as a Director of the Development and Technology Transfer Directorate, and three years for the UN initiated Millennium Village Project (MVP) as an Agriculture and Environment Coordinator. Concurrently, over the years, he had also extensively taken part in the teaching endeavors of various universities in Ethiopia, including Jimma, Mekelle, Haramaya, and Bahir-Dar and offered various courses at various levels (i.e. diploma, undergraduate and postgraduate), i.e. Herbs and Spice Production, Fruit Production, Vegetable Production, Postharvest Technology, Seed Technology, and Floriculture & Landscape Designing. In addition to his pioneering and exemplary contributions in the introduction of vanilla, cola nut and areka nut to Ethiopia, the author is as well a founding member of the Ethiopian Horticultural Science Society (EHSS). Following his 15 years of consequetive contribution as a Secretary, he is now serving as a member of the Advisory Committee to the Society. He finally joined the School of Graduate Studies of Jimma University College of Agriculture and Veterinary Medicine (JUCAVM) where he has been pursuing his study in horticulture with his dissertation research based on the above stated topic on banana.

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PUBLISHED ARTICLES

Zenebe Woldu, Ali Mohammed, Derbew Belew, Zekarias Shumeta and Adam Bekele. 2015. Assessment of Banana Production and Marketing in Ethiopia**.** *International Journal of Sciences: Basic and Applied Research, 24(3): 283-307*

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Zenebe Woldu, Ali Mohammed, Derbew Belew, and Tarekegn Argaw. 2015. Effect of Traditional Kerosene Smoking and Ethrel on Ripening, Shelf Life and Quality of Cavendish Banana *(Musa spp.)*. *African Journal of Agricultural Research,50(2):4570-4583.*

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LIST OF ABBREVIATIONS AND ACRONYMS

ANOVA	Analysis of Variance
ATA	Ethiopian Agricultural Transformation Agency
Birr	Ethiopia Currency
CFC	Common Fund for Commodities
CODEX-CODEX	Alimentarius (a collection of internationally recognized food standards)
CSA	Central Statistics Agency of Ethiopia
Degree Brix (^{0}Brix)	Degree Brix (sugar content of an aqueous solution)
EHDA	Ethiopian Horticulture Development Agency
EIAR	Ethiopian Institute of Agricultural Research
ETFRUIT	Ethiopian Fruit and Vegetables Marketing Share Company
FAO	Food and Agriculture Organization of the United Nations
FAOSTAT	Statistics Division of FAO
HDPE	High Density Polyethylene
ICAR	Indian Council of Agricultural Research
JUCAVM	Jimma University College of Agriculture and Veterinary Medicine
LDPE	Low Density Polyethylene
LIVES	Livestock and Irrigation Value-Chains for Ethiopian Smallholders
MAP	Modified Atmosphere Packaging
N	Newton (IS unit of ‘force’)
NGOs	Non-Government Organizations
RCBD	Randomized Complete Block Design
PEP	Polyethylene Package
SAS	Statistical Analysis System
SNNPRS	Southern Nations Nationalities and Peoples Regional State of Ethiopia
SNV	Netherlands Development Organization (Ethiopia)
SPSS	Statistical Package for the Social Sciences
Vita	A foreign registered charity organization implementing agriculture and livelihood projects in Gamo-Gofa Zone (Ethiopia)
WHO	World Health Organization

GENERAL ABSTRACT

The present study was initiated with an overall objective of assessing the current banana pre and post harvest management practices, identify the gaps, develop appropriate technologies on selected post harvest quality determinants in Ethiopia. Econometric models and descriptive statistics were employed to study the yield performance of banana in the study areas. Results indicate that different household and farm characteristics including age, household size and experience in banana production, area of land allocated and method of banana production (irrigated or rainfed), spacing and type of planting material used, household head (male or female-headed), extension service, membership of farmer cooperatives/unions, etc. affect the yield of banana in the study areas.

About 13 marketing channels were identified across the banana supply chain in Ethiopia. Results of channels that terminate within domestic markets show Gross Marketing Margins ranging 29.2%-43.8% for small-scale growers, 33.3%-45.8% for large-scale commercial growers, 16.7%-43.8% for cooperatives/unions, 4.8%-12.5% for farm-gate collectors, 25%-37.5% for wholesalers/ripeners, and 29.17%-50% for retailers. Results generally indicate that even though the country has vast potential for banana production, the supply chain is facing several limitations and constraints that include high variability in crop management practices and yield and highly deregulated marketing practices that result in excessively high price and marketing margin disparities across the numerous channels. These points out the need for increased research and extension services, and improvement in marketing logistics and channel management.

The study on post-harvest handling practices and loss of banana in Ethiopia indicated that the aggregate post-harvest loss of banana was 45.78%, of which about 15.68% was incurred at farm, 22.05% at wholesale (including transport from farm gate and ripening), and 8.05% at retailer or purchase to end-user sale levels. Of the causes of postharvest loss accounted during banana transport from the farm gate, impact and finger breakage damages purely accounted to 20% while the remaining 80% also included physiological and other mechanical damages. Results of the multiple regression analysis indicate that market distance, duration of transport, storage condition, storage duration, duration of ripening, type of ripening rooms, and means of bunch

transport and experience in banana marketing were important determinants of the post-harvest loss of banana in Ethiopia. The study generally indicate that even though the country has vast potential for banana production, the supply chain is facing several limitations and constraints that include high yield variability, crop management practices, and high produce perishability and post-harvest losses throughout the handling stages. These suggests to the need for increased research and extension services as well as improvement in postharvest handling (transportation, storage, packaging and ripening) and marketing infrastructure and facilities.

The first laboratory-based experiment was conducted to address the key challenge the country is facing in terms of fresh banana exports using the costly temperature controlled (14^{o}C) reefer containers rented from maritime companies abroad. It was specifically carried out to investigate the combined effects of two factors (1-MCP concentrations and export standard packaging materials) on shelf life and physicochemical quality attributes of Cavendish banana (*Musa* AAA Group, Cavendish Subgroup, cultivar 'Poyo', syn: 'Robusta') under ambient conditions (22$\pm$1 °C and 80 $\pm$ 5% RH). Results indicate that 1-MCP treatment with increased levels of concentration and increased levels of modified atmosphere packaging (MAP) generally extended shelf life and maintained better quality of fresh banana fruits when applied separately and in combination. The longest shelf life (36 days) with the lowest changes in physicochemical properties was obtained when fruits were kept in corrugated cardboard boxes with inner sealed or non-perforated polyethylene bags (PEP) after treatment with the highest concentration of 1-MCP 17.5µl/L. This could be attributed to the higher inhibitory effect of 1-MCP on both the synthesis and action of ethylene when applied at the highest level of concentration and the stronger modified atmosphere (MA) condition created by the inner non-perforated PEP kept within the corrugated cardboard boxes. This technique could be considered as a less sophisticated and less costly postharvest handling alternative (storage and transportation) under ambient conditions to the temperature controlled (14^{o}C) reefer container-based system currently employed in Ethiopia and elsewhere for fresh banana exports.

The second laboratory-based experiment was aimed at finding less sophisticated and less costly banana ripening technique compared to the currently employed traditional kerosene smoking system, which is globally known to have several setbacks in terms of its overall management and

subsequent effects on the physicochemical quality attributes of the banana fruits. All parameters tested were invariably and progressively affected by the treatment combinations over the experimental period. A three way significant ($P \leq 0.05$) interaction effect of the three factors was revealed on the 7th day of the ripening period on the major quality parameters, starch, TSS, and TSS:TA. Sensory quality evaluation results conducted on the 7th day of the ripening period also showed similarly highly significant interaction effect among the treatment factors on all quality attributes tested. Ethrel treated fruits demonstrated higher mean sensory quality score values in color (3.85), flavor (3.89), taste (3.80), aroma (3.66) and total acceptability (3.67), other than mouth feel (3.37). Fruits treated with all treatment combinations of the kerosene smoking system equally completed their maximum ripening stage on the 7th day of the ripening period. However, at this stage, fruits were found developing some off-ripening effect black scars on the peel in addition to the relatively low quality attributes recorded upon them through the sensory evaluation panel. Fruits treated with ethrel completed their ripening stage on the 7th day only at the exposure time of 30 h. Those exposed to 18 and 24 h exposure times took more time and extended their ripening stage to up to the 11th day. Thus, in terms of ripening efficiency, the kerosene smoking system can be used at the lowest exposure time of 18 h. The ethrel-based ripening system can similarly be used for equal ripening efficiency as well as better sensory quality attributes at the highest exposure time of 30 h.

Keywords: *Banana, export standard packaging, ethrel, gross marketing margin, kerosene smoking, physicochemical quality, postharvest losses, ripening, shelf-life, supply-chain, yield, 1- Methylecyclopropene (1-MCP)*

CHAPTER 1: GENERAL INTRODUCTION

1.6. Background

Banana is the common name used for herbaceous plants in the genus *Musa,* which belong to the family *Musaceae*. The genus *Musa* basically comprises the two groups of banana broadly referred to as dessert (*M. acuminate)* and cooking or plantain *(M. Balbisiana*) types. The total number of cultivars of bananas and plantains has been estimated to be anything from around 300 to more than 1000 (Chia, 1981; Huggins *et al*., 1990).

Bananas are native to tropical southern and southeastern Asia but are widely cultivated in a wide variety of climates ranging from the wet tropical to the subtropical regions (Ploetz1, 2005; Jain and Priyadarshan, 2009; Voldeck, 2010). Secondary centers of banana diversity, both desert and cooking types, are also developed later in the highland and coastal areas of East Africa, West Africa and Latin America (Ploetz1, 2005).

Bananas (*Musa spp.*) are the fourth most important staple food crops in the world after rice, wheat and maize (Salvador *et al*., 2007). Cultivated by about 130 countries, they are the most widely grown fruit crops in the world (Osava, 2003). They are also highly valued for their nutritive value and role in stabilizing the environment, protecting soil from erosion, providing habitats for biodiversity, feeding animals and increasing aesthetic appeal of landscapes (Bagamba, 2007).

Cultivated bananas are *parthenocarpic* (virgin fruit or fruit produced without fertilization of ovules), which makes them sterile and unable to produce viable seeds (Ploetz1, 2005; Jain and Priyadarshan, 2009; Voldeck, 2010). Bananas, which are not producing seeds, are propagated vegetatively by dividing the underground stem (called a corm), suckers (vertical shoots that develop from the base of the pseudostems) or commercially by means of tissue culture plantlets.

Being climacteric fruits, bananas enters the ‘climacteric phase’ or ripening after harvest. During the ripening process the fruits undergo compositional change by emitting ethylene alongside the increase in the rate of respiration to attain their desirable flavor, quality, color, palatable nature and other textural properties (Ploetz1, 2005; Jain *and* Priyadarshan, 2009; Voldeck, 2010).

Dessert banana in particular is a commercially important crop in the global trade, both by volume and value, as a leading desert fruit (Salvador *et al*., 2007). According to FAOSTAT (2014), the average world production and area coverage of banana between 2009 and 2013 was 104,955,497 tons and 5,031,333.6 hectares, respectively whereas the world banana export was estimated to be 16, 494,800 tons in 2012. Developing countries accounted for the bulk of the exports. For instance, Africa's export share was about 3.9 percent of the global export in 2012 and the value was estimated to be 648,800.0 tons.

According to FAOSTAT (2014), the 11 major banana producing countries that accounted for about 75% of total banana production are located in the developing world, which include India, Tanzania, Brazil, Philippines, China, Burundi, Ecuador, Uganda, Angola, Indonesia and Viet Nam. On the other hand, FAOSTAT (2014) documented the major world banana importing countries as being USA, Belgium, Germany, Japan, Russia, UK, Iran, Italy, France, Canada, Argentina, Republic of Korea, Saudi Arabia, Poland, Netherlands and Turkey in that order of importance. The same source indicated that in Africa, the major banana producer countries included Côte d'Ivoire, Cameroon, Ghana, Tanzania, Burundi, Uganda, Angola, DR of Congo, and Kenya.

Similarly, banana is the most important fruit crop in Ethiopia, both in terms of production and consumption. It grows in several parts of Ethiopia where the growing conditions are favorable. Of the 90,070.83 hectares of land covered by different fruit crops, about 59.64% is occupied by banana. In 2013/14 production year, about 706,648.6 tons of fruits were produced, of which banana took up 68.00% (CSA, 2014).

The Southern Nations Nationalities and Peoples' Regional State (SNNPRS) is the major banana producer in Ethiopia, covering 37,076.85 and 1,784.39 hectares of land and 370,784.2 and 16,620.8 tons banana production in 2013/14 under small-scale and large-scale production systems respectively (CSA, 2014).

The major dessert banana cultivars currently grown in Ethiopia are Poyo, syn.: Robusta, Dwarf Cavendish and Giant Cavendish. More than 90% of the produce currently marketed and consumed in Addis Ababa and other major towns of Ethiopia comes from these three cultivars

(CFC, 2004). Others like Williams I & II, Grand Naine, and Butuzua are also among the relatively recently released cultivars in Ethiopia. Besides, there are some less popular land race cultivars grown in certain localities across the country.

As reported by FAOSTAT (2014), Ethiopia also exported 4100 tons of bananas in 2012 largely to the neighboring countries of Djibouti and Somaliland. Similarly, trial banana shipments of about 80 tons were exported to Saudi Arabia (Jeddah) in 2012 from Gamo-Gofa zone using temperature controlled reefer containers rented from maritime companies abroad (EHDA, 2012). The report stated that this trend was planned to continue with an export of 1000 tons per month; but could not be realized due to the excessively high round trip rental cost of the reefer containers (7500-8000 USD) to the destination market in Jeddah (i.e. from the farm gate in Arba-Mich). Other additional miscellaneous inland costs such as custom taxes and service charges for quarantine certification were also reported as part of the overall challenge facing the banana export from Ethiopia.

Although the demand for banana in Ethiopia is steadily increasing from time to time, it is so far grown only on less than 01% of the gross cropped area, contributing less than 0.8% of the gross value of agricultural outputs and quite negligible in export earnings (CSA, 2009). Banana production and marketing in Ethiopia is challenged by numerous pre and postharvest constraints that ultimately cause yield and quality losses. The major reasons for these are reported to be inadequate production and management conditions in the field, inappropriate harvest maturity determination, as well as rough and rudimentary harvesting, loading and transporting, unloading and ripening conditions, and whole and retail marketing systems (CFC, 2004; Dawit Alemu and Asmare, 2008; EHDA, 2012).

In general, banana has not been given priority that it actually deserves in Ethiopia. Although there are some reports that indicate about some studies carried out in certain pocket areas, no significant and reliable information is so far available in Ethiopia at large scale regarding the status and scale of the factors that determine the production, marketing and postharvest losses of banana at different stages across the supply chain.

It is with this background that this PhD dissertation research was proposed. The research approach was designed in a way to assess the current production, marketing as well as postharvest management practices, identify the gaps and thereby undertake certain laboratory based experiments on some of the key postharvest problem areas.

1.7. Statement of the problem

Although Ethiopia has great potential to produce high quality banana, the postharvest management and marketing practices are still not standardized/optimized across the supply chain. The perishable nature of banana fruits particularly requires careful harvesting and postharvest handling to reduce both quantitative and qualitative losses and thereby meet local and export standards to ensure better price to farmers and hard currency to the country at large.

Taking into account that postharvest management/technology begins from harvest maturity determination and beyond, the overall factors that are limiting the maximum exploitation of banana in Ethiopia include**:** inadequate pre-harvest management practices (choice of planting materials, cultural practices and pest and disease management), faulty harvest maturity determination and crude harvesting techniques, rough farm-gate and subsequent bunch handling practices (loading, transport, unloading and storage), absence of appropriate postharvest treatments (cooling, washing, sorting, grading, and application of disinfectants and ethylene scrubbers), and rudimentary marketing facilities and practices (ripening, packaging, distribution/cool-chain management and produce display).

Research done and overall interventions made in Ethiopia across these areas is very little in that pre- and postharvest factors that affect the shelf life and quality of banana are so far not well studied. Furthermore, no extensive assessments have been done to identify and quantify the type and extent of the various postharvest losses and subsequent mitigation strategies have not been developed for implementation all across the supply chain. However, provided that the basic postharvest management systems/standards for the crop are well developed/determined, significant interventions could be made into the existing system (i.e. Conventional pre and postharvest practices) by piloting and scaling up the results all across the country.

Thus, since the ultimate use of banana for subsistence and commercial production depends upon many pre-harvest and postharvest factors, studies like this one would be unequivocal in this direction.

1.8. Research questions

(1) What are the current banana production and marketing practices as well as associated problems in Ethiopia?

(2) What are the current banana postharvest handling practices and associated cuases of losses in Ethiopiopia?

(3) Can ethrel solution (*2-chloro ethyl phosphonic acid; syn.: Ethephon,* $C_2H_6ClO_3P$) be a better alternative to the conventional kerosene smoking-based banana ripening system in Ethiopia?

(4) Can 1-MCP (*1-Methylecyclopropene,* C_4H_6), in combination with the currently used export standard packaging materials, be equally effective and a less costly alternative to the currently employed temeperature controlled reefer container-based fresh banana export system in Ethiopia?

1.9. Objectives

1.9.1. General objective

To assess the current banana pre and postharvest management practices in Ethiopia, identify the gaps, and develop appropriate technologies on key postharvest quality determinants.

1.9.2. Specific objectives

(1) To assess problems associated with the current banana production and marketing practices in Ethiopia

(2) To assess the current banana posts harvest practices and losses in Ethiopia

(3) To determine the combined effects of 1-MCP (*1-methylcyclopropene*) and export standard packaging materials on shelf-life and quality of fresh banana fruits destined for export purposes

(4) To determine the effect of the traditional kerosene smoking and ethrel solution (syn.: ethephon, *2-chloro ethyl phosphonic acid)* generated ethylene on ripening and quality of Cavendish banana cultivars

5) To generate baseline information for future technical and policy interventions

1.10. Significance of the study

The study was deigned to generate useful information on the current banana pre and postharvest practices, including marketing, in Ethiopia and will serve as a baseline input for researchers, extension workers as well as policy makers or development planners to formulate strategic plans for appropriate interventions. Since the study was intended to uncover the present pre and postharvest management gaps, i.e. in terms of productivity and quality limitations, postharvest losses, and marketing constraints, the potential users of the findings (i.e. producers, traders and postharvest handlers, research and extension institutions, including other government and non-government organizations) will find it easier to streamline their activities and resources all along the whole supply chain.

CHAPTER 2: LITERATURE REVIEW

2.1. Botany and Origin of Banana

Banana is the common name used for herbaceous plants in the genus *Musa,* which belong to the family*Musaceae*. The genus *Musa* basically comprises the two groups of banana broadly referred to as dessert and cooking (plantain) types. The total number of cultivars of bananas and plantains has been estimated to be anything from around 300 to more than 1000 (Chia, 1981; Huggins *et al*., 1990).

Bananas are known to have been derived from *M. acuminata* and *M. Balbisiana,* which are classified into cultivar groups using two criteria (Chia, 1981; Huggins *et al*., 1990). The first is the number of chromosomes: whether the plant is diploid, triploid or tetraploid. The second is relationship to the two ancestral species, which is often determined by genetic analysis (genomics) or by a scoring system. A cultivar is scored on 15 characters, chosen because they differ between the two species. Each character is given a score between one and five according to whether it is typical of *M. acuminata* or *M. balbisiana* or is in between. Thus the total score for a cultivar will range from 15 if all characters agree with *M. acuminata* to 75 if all characters agree with *M. balbisiana*. Groups are then named using a combination of the letters "A" and "B". The number of letters shows the ploidy; the proportion of As and Bs shows the contributions of the ancestral species. The AAB Group, for example, comprises triploid cultivars with more genetic inheritance from *M. acuminata* than *M. balbisiana*. A character score of around 35 is expected for members of this group. Within groups, cultivars may be divided into subgroups and then given a cultivar name, e.g. *Musa* AAA Group (Cavendish Subgroup) 'Robusta'.

Bananas are native to tropical southern and southeastern Asia but are widely cultivated in a wide variety of climates ranging from the wet tropical to the subtropical regions (Ploetz1, 2005; Jain *et al*., 2009; Voldeck, 2010). Secondary centers of banana diversity, both desert and cooking types, are also developed later in the highland and coastal areas of East Africa, West Africa and Latin America (Ploetz1, 2005).

Cultivated bananas are *parthenocarpic (*virgin fruit or fruit produced without fertilization of ovules), which makes them sterile and unable to produce viable seeds *(*Ploetz1, 2005; Jain *et al*., 2009; Voldeck, 2010). Having no seeds, bananas are propagated vegetatively by dividing the underground stem (called a corm), suckers (vertical shoots that develop from the base of the pseudostems) or commercially by means of tissue culture plantlets. While the use of plantlets ensures disease-free planting materials, the use of suckers and corms is often bound with a risk of transmitting diseases and nematodes (e.g. the devastating Panama disease).

Bieng climacteric fruits, bananas enter the 'climacteric phase' or ripening after harvest. During the ripening process the fruits undergo compositional change (from starch into simple sugars) by emitting ethylene alongside the increase in the rate of respiration to attain their desirable flavor, quality, color, palatable nature and other textural properties (Ploetz1, 2005; Jain *et al*., 2009; Voldeck, 2010).

2.2. Uses of Banana

As stated by Chia (1981) and Huggins *et al*. (1990), different parts of the banana plant are used for a wide range of purposes. Banana fruit may be eaten raw or as a cooked vegetable. The fruit can also be processed for a number of food products. Ripe fruits can be pulped for puree for use in a variety of products including ice cream, yogurt, cake, bread, nectar, and baby food. Ripe bananas can be dried and eaten, or sliced, canned with syrup, and used in bakery products, fruit salads, and toppings. Green (unripened) bananas can be sliced and fried as chips. Whole green fruits can also be dried and ground into flour. Vinegar and alcoholic beverages can be made from fermented ripe bananas. Other parts of the banana plant are consumed besides the fruit. The heart of the growing pseudostem is eaten in India. In Southeast Asia, the male bud is eaten as a boiled vegetable. The banana leaves are not eaten but may be used for wrapping food in cooking. The banana foliage and pseudostems are used as cattle feed during dry periods in some banana producing areas. Culled bananas are used as animal feeds. Bananas contain about 74% water, 23% carbohydrate, 1% protein, and 0.5% fat. The fruits are also known to be good sources of potassium, calcium, phosphorus and vitamin C. In lower concentrations, they also contain vitamins A, thiamine, riboflavin and niacin (Ferguson, 2002).

2.3. Status of Banana Production and Export

Banana and plantain (*Musa spp.*) are the fourth leading food crops worldwide, after rice, wheat and maize (Salvador *et al*., 2007). Cultivated by about 130 countries, they are the most widely grown fruit crops in the world (Osava, 2003).The Cavendish banana types (belong to the Cavendish subgroup of the AAA genome cultivars of *Musa acuminate*), which are known to account for about 47% of the global banana production, are the most important cultivars in the international trade (Ploetz1, 2005; Jain *et al*., 2009; Voldeck, 2010). The average world production and area coverage of banana between 2009 and 2013 was 104,955,497 tons and 5,031,333.6 hectares respectively (FAOSTAT, 2014). Similarly, the average production and area coverage of banana in Ethiopia in the year 2013 were 274,585.6 tons and 33,635.2 hectares respectively (FAOSTAT, 2014).

According to FAOSTAT (2014), the 11 major banana producing countries that accounted for about 75% of total banana production are located in the developing world, which include India, Tanzania, Brazil, Philippines, China, Burundi, Ecuador, Uganda, Angola, Indonesia and Viet Nam. On the other hand, FAOSTAT (2014) puts the major world banana importing countries as being USA, Belgium, Germany, Japan, Russia, UK, Iran, Italy, France, Canada, Argentina, Republic of Korea, Saudi Arabia, Poland, Netherlands and Turkey in that order of importance. In Africa, the major banana producer countries were put as being Tanzania, Burundi, Uganda, Angola, DR of Congo, Cameroon, and Kenya averagely producing 16, 342,539 tons of banana from 2009 -2013 (FAOSTAT (2014).

FAOSTAT (2014) puts the world banana export in 2012 at 16, 494,800. 0 tons and indicates developing countries to account for the bulk of the exports (Table 2.1). Africa's exports, which accounted for 3.9 percent of global banana shipments, grew by 2.4 per cent in 2012 as exports reached 648,800.0 tons (FAOSTAT, 2014). As depicted in Table 2.1, banana exports from

Ethiopia are by and large to the neighboring countries, Djibouti and Somaliland, and are comparatively so negligible.

Table 1. Trends of world and regional banana gross exports (1000 tons), 2008-2012.

Exporters	2008	2009	2010	2011	2012
Asia	2305.7	1857.4	1764.9	2217.4	2817.9
Latin America & Caribbean	955.0	12 345.8	11 771.7	12 527.0	13 028.0
Central & South America	687.8	11 976.2	11 392.2	12 202.0	12 705.4
Africa (total)	611.4	568.2	643.5	633.7	648.8
World (total)	14 872.3	14 771.4	14 180.2	15 378.3	16 494.8
Ethiopia	2.0	2.8	3.6	4.1	4.1

Source: FAO (2014)

Banana grows in several parts of Ethiopia where the growing conditions are favorable. As reported by CSA (2014), the number of holders practicing fruit production in Ethiopia is generally much less than that of grain crops. As shown in Table 2.2, only about 90,070.83 hectares of land is under fruit crops in Ethiopia, of which banana accounts for about 59.64%, followed by avocado (15.19%). In the 2013/14, about 706,648.6 tons of fruits were produced in Ethiopia, of which banana, mango, avocado, papaya, and orange took up 68.0%, 13.0%, 8.0%, 6.00% and 4.0% respectively (Table 2. 2). Conversely, as shown in Table 2.3, the area covered by banana in Ethiopia under large scale commercial productions stands third (1,910.97 ha) next to orange (2,454.24 ha) and mango (2,365.96 ha).

As shown in Tables 2.4 and 2.5, the Southern Nations Nationalities and Peoples' Regional State is the major banana producer in Ethiopia both under small-scale and large-scale production systems (CSA, 2014).The Arba-Minch, Mizan and Tepi areas are by far the largest producers of banana in Ethiopia. About 85% of the total national production comes from these three localities. Among the three localities, the Arba-Minch area comes on the top as 70% of total production of banana in the country comes from it. Then comes Mizan area with 10%, and Tepi area with 5% of the total production. In those localities, there are a lot of factors that favor the production of banana. These factors include availability of fertile soil, adequate rainfall and water resources for irrigation, suitable climate, and well experienced farmers.

Table 2: Area, production and yield of fruit crops, under private peasant holdings in Ethiopia, 2013/14

Crop	Number of Holders	Area coverage		Production (tons)	% Distribution	Yields (tons/ha)
		ha	%			
Banana	2,574,035.00	53,956.16	59.64	478,251.0	68.00	8.9
Avocado	1,382,199.00	13,798.04	15.19	53,697.8	8.00	4.0
Mango	1,146,419.00	12,860.54	14.09	90,561.4	13.00	7.2
Papaya	572,313.00	2,434.14	2.66	40,435.1	6.00	17.2
Orange	454,707.00	3,298.97	3.64	31,427.7	4.00	9.7
Guava	331,529.00	2,830.24	3.14	3,932.3	1.00	1.4
Lemon	222,942.00	1,238.77	1.37	7,903.8	1.00	6.4
Pineapple	36,797.00	251.35	0.27	*	*	*
Total	6,720, 941.00	90,070.83	100.00	706,209.1	100.00	-

*Data not available

Source: CSA (2014)

Table 3: Area, production and yield of fruit crops, under commercial farms in Ethiopia, 2013/14

Crop	Area coverage		Production		Yield
	Hectares	%	Tons	%	Tons/ha
Orange	2,454.24	0.25	32,762.3	0.40	13.4
Mango	2,365.96	0.24	18,937.9	0.23	8.0
Banana	1,910.97	0.19	17,924.6	0.22	9.4
Papaya	716.25	0.07	32,223.6	0.39	45.0
Avocado	145.64	0.01	1,184.5	0.01	8.1
Lemon	48.25	*	365.0	0.01	7.6
Guava	43.23	*	162.2	*	3.8
Pineapple	16.14	*	21.9	*	1.4
Total	7,700.69	0.78	103,582 .0	1.27	-

*Data not available; Source: CSA (2014)

Table 4: Status of banana production across National Regional States in Ethiopia (Private Peasant Holdings), 2013/14

Region	Number of holders	Area (ha)	Production (tons)	Yield (tons/ha)
Tigray	9,196.00	*	*	*
Afar	*	*	*	*
Amhara	133,160.00	1,187.76	2,676.2	2.3
Oromia	883,278.00	13,412.90	94,555.6	7.1
Somali	4,592.00	*	*	*
Benishangul-Gumuz	34,811.00	1,002.27	4,248.9	4.2
SNNP Region	1,504,207.00	37,076.85	370,784.2	10.0
Gambela Region	11,355.00	234.61	*	*
Harari	3,092.00	11.81	*	*
Dire Dawa	986.00	3.63	*	*

Source: CSA (2014); *Data not available

Table 5: Status of banana production across National Regional States in Ethiopia (Commercial Farm Holdings), 2013/14

Region	Area coverage		Production		Yield (tons/ha)
	(ha)	%	(ton)	%	
Tigray	1.27	*	10.0	*	7.9
Afar	*	*	*	*	*
Amhara	94.67	0.05	1,039.6	0.35	11.0
Oromia	27.71	0.01	234.6	*	8.5
Somali	2.63	0.22	19.5	0.22	7.4
Benishangul-Gumuz	0.30	*	0.1	*	0.2
S.N.N.P. Region	1,784.39	1.30	16,620.8	4.17	9.3
Gambela Region	*	*	*	*	*
Harari	*	*	*	*	*
Dire Dawa	*	*	*	*	*
Total Ethiopia	1,910.97	0.19	179,24.6	0.22	-

Source: CSA (2014); *Data not available

As stated by CFC (2004), the major dessert banana cultivars currently grown in Ethiopia are Poyo, syn.: Robusta, Dwarf Cavendish and Giant Cavendish. More than 90% of the produce currently marketed and consumed in Addis Ababa and other major towns of Ethiopia comes from these three cultivars. Others such as Williams I & II, Grand Naine, and Butuzwa are also among the recently released cultivars in Ethiopia. Besides, there are some less popular land varieties grown in certain localities across the country. Du-Casse Hybrid, locally commonly known as “Kenya Muz” or “Kenya Banana” is also widely grown by smallholder farmers usually along the borders of homestead and home-farm stead farmlands primarily because of its strong wind and moisture stress tolerance. Although it is known as a triploid ‘ABB’ genome type cooking banana elsewhere, it is locally grown and consumed similar to the other dessert types. Table 2.6 below shows some peculiar characteristics of the above stated cultivars.

Table 6: Brief description of the major dessert banana cultivars grown in Ethiopia

Cultivar	Genome (Triploid AAA)	Vernacular name (Gamo-Gofa)	Scale of production	Major producers	Av. PH (cm)	No. DF	No. DH	DFH*	Av. Yield/ha (ton)**	Av. BW. (kg)*	Av. NH/B	Av. NF/H**	Av. HW (kg)**
Poyo ; syn: Robusta	AAA	"Mekakelegn a Ambo"	Very wide	Small & large-scale	192**	206.6**	376.6**	114	33.0	12.0	5.2**	63.5	8.2
Dwarf Cavendish	AAA	"Dinke"	Wide	"	103**	228.0**	311.7**	126	45.3	15.9	6.7**	80.0	10.0
Giant Cavendish	AAA	"Rejimu Ambo"	Moderate	"	190**	234.8**	483.0**	118	42.0	14.1	5.3**	79.0	9.0
Williams-1	AAA	-	Limited	Mostly large-scale	206*	244.0*	345.0*	114	21.3	16.0	8.0*	45.3	8.2
Williams-2	AAA	-	Limited	"	206*	244.0*	345.0*	121	20.0	16.0	8.0*	49.0	7.0
Grand Naine ("Chiquita banana)	AAA	-	Limited	"	214*	213.0*	307.0*	129	33.3	23.0	8.0*	58.7	7.6
Butuzua	AAA	-	Limited	"	180**	188.0**	399.7**	114	22.7	8.8	6.7**	46.0	7.2
Valery	AAA	-	Limited	"	-	-	-	-	9.5***	-	-	-	-
Local types	AAA	"Yabesha Muz"	Wide	Small-scale	320**	214.8**	580.9**	-	18.5	-	4.3**	27.0	3.2
Ducasse Hybrid (Pisang Awak)	ABB ****	"Kenya Muz"	Wide (small-scale)	Small-scale	-	-	-	-	-	-	-	-	-

Where: DFH=Days from flowering to harvest; Av.BW=Average bunch weight; Av. NH/B=Average number of hands per bunch; Av. NF/H=Average number of fingers per hand; Av. HW=Average hand weight; No.DF= Number of days to flowering; No. DH= Number of days to harvest; Av.PH= Plant height

Sources:

*Tesfa et al. (2015); ** Tekle et al. (2014); ***TARC (2014)

**** Elsewhere out of Ethiopia, used as a triploid (ABB) cooking type banana

2.4. Banana Marketing and Postharvest Handling Practices in Ethiopia

Other than those grown in Gamo-Gofa zone, banana fruits produced by smallholder growers are mostly marketed at local outlets, with only a little portion transported to relatively distant terminal markets within Ethiopia. In the later case, the fruits are transported by trucks piled in lose bunches.

Although the bananas are generally clean in appearance in the field, the quality presented in the local markets is generally poor. They are also liable for various postharvest damages that account for about 30-40 % losses (CFC, 2004). According to various sources, including this one, the causes of such high level of postharvest losses of banana are variously and broadly attributed to the following conditions that the produce faces as it moves along the supply chain.

Conditions in the field –various management practices are not receiving good attention, e.g. fertilization and sucker management are seldom practiced.

Conditions during harvesting–farmers generally do not have good experience with regard to appropriate harvest maturity determination and the harvesting process is rough and not done properly.

Conditions at farm-gate collection centers- bunches transported without proper care and piled up over each other, in most cases without proper shade waiting for trucks that in most cases do not come in time.

Conditions during loading and transporting –workers are not fully aware of the right way of loading and trucks are usually overloaded with piles of bunches. At times, people along with their luggage are travelling together with the banana while seated on the top of the load. Besides, trucks as they leave the farm-gate collection centers have to first pass through long bumpy gravel access roads before reaching the relatively asphalted highway. As the produce travels to the central or regional destination markets, there are also several checkpoints where the drivers have to stop for checking their load and documents. It is also not uncommon to observe truck drivers wasting a lot of time resting at service or utility areas along the way. This situation is even worse during the rainy season as trucks often get stacked in the muddy farm-gate roads. The produce is normally lifted from the farm by human carriage, rarely by animal driven-carts, and thus several trips are required to fill up one truck load, which extrapolates to more handling, more cost and delay to the produce.

Conditions during unloading and placing of bunches to the ripening rooms- upon arrival at the wholesale places, the handling of bunches is often similarly so rough. The common practice is such that bunches are thrown from the truck to a man waiting beside and he in return will throw them to the ground. After unloading, bunches are weighed and piled on the floor of the ripening room almost up to the roof. As such air circulation is severely hampered and bunches further cause compression damage to the ones underneath. The ripening rooms are seldom cleaned or washed and so they often become conducive for the growth of microorganisms.

Conditions during ripening-other than the different farm level traditional ripening systems in underground pits and above ground piling with different grass and straw covering materials, the relatively commercial banana ripening system employed in Ethiopia is by placing the bunches inside air-tight rooms locally known as "Chella" or "Muket" houses. This local term to the system often refers to the high temperature, CO_2 build up in the ripening rooms and to the absence of a ventilation system. Ripening is carried out in such rooms without any device for proper regulation of air-circulation, temperature and humidity. It is simply done by placing the bunches directly into the rooms to expose them for two to four days, depending on the prevailing temperature of the locality, by kerosene smoking or use of kerosene burners inside smoke chambers. After initiation of ripening, bunches are then withdrawn from the air-tightly sealed rooms and distributed to retailers after dehanding. The smoke emitted by the kerosene burners is not only ethylene but also acetylene gas (Anon, 2015). The other drawback of this ripening method is that the persistence of the smoke odor often impairs the quality of fruits and thus fruits may not deliver the desired uniform color and flavor to consumers (Anon, 2015)

Conditions at retail marketing –selling of banana by retail is locally conducted in the central and regional markets, green grocers, supermarkets, traditional open sun markets and roadside stands. Here again, the handling of the fruits is so rudimentary, as they are in most cases exposed to the direct sun and various contaminants.

2.5. Overall Fruit Quality Attributes and Grade Standards for Banana Marketing

As defined by Shewfelt *et al*. (2000), quality is broadly defined as ‘fitness for purpose’. Fruit quality is similarly defined as being the composite of its characteristics that impart value to the buyer or consumer (Kader, 2002). Fruit quality relates to several factors that can be commodity specific and mean different things to different people. While consumers consider good quality fruits to be those that look good, are firm and of good flavor and nutritive value, producers and handlers are concerned first with appearance and textural quality along with long postharvest life (Kader, 2002). Considering the increasing divergence in the perception of fresh produce quality among the supply chain actors, Thompson (1995) stated that the present management of quality has moved from produce-orientated trade to market-orientated business. Getting the fresh produce to any market means involving different people and organizations as it passes through the chain. This modern concept of supply chain management ultimately brings about improved profitability to all chain participants (Thompson, 1995; Hewett, 2003).

As stated by Jongen (2000), fruit quality is made up of many attributes, both intrinsic and extrinsic. Intrinsic features of the fruit include key external attributes such as colour, shape, size and freedom from defects. In addition, internal attributes include texture, sweetness, acidity, aroma, flavour, shelf life and nutritional value. These are important components of the subjective approach used by the consumer in deciding what to purchase. Extrinsic factors refer to production and distribution systems. These factors include chemicals used during production, package types, sustainability of production and its distribution system. These extrinsic factors are likely to influence consumer’s decision to purchase rather than to reflect on the actual quality of the fruit. On the other hand, intrinsic and hiden factors influence the repurchasing decision of consumers.

In line with this, Fritschel (2003) stated that fruit quality is primarily determined in the field in that postharvest technologies can only maintain its quality, not improve it. Thus, it is critically important that producers understand how a multitude of preharvest factors can interact to influence fruit quality during and after harvest so that they can ultimately ensure the delivery of only the highest quality fruits into the supply chain (Bowersox *et al*., 2003; Collins, 2003). In banana and other climacteric fruits, quality is primarily and more intimately related to both physiological and commercial maturity. Physiological maturity is the stage of development when a plant or plant part will continue ontogeny even if detached (Shewfelt, 2000). Commercial maturity often equates to ripeners' and is the stage of development when the fruits possess the prerequisites for utilization by consumers (Shewfelt, 2000).

CODEX standard for bananas (CODEX STAN 205-1997, AMD. 1-2005)

Codex Alimentarius is a collection of internationally recognized standards, codes of practice, guidelines and other recommendations relating to foods, food production and food safety (WTO, 2015). Its texts are developed and maintained by the Codex Alimentarius Commission, a body that was established by the Food and Agriculture Organization of the United Nations (FAO), which was later joined by the World Health Organization (WHO). The main goals are to protect the health of consumers and ensure fair practices in the international food trade. It is now recognized by the World Trade Organization as an international reference point for the resolution of disputes concerning food safety and consumer protection (WTO, 2015). Thus, according to the Codex Alimentarius Commission, the following are the CODEX Standard Specifications stipulated for commercial varieties of dessert bananas grown from Musa spp. (AAA), of the Musaceae family, in the green state, to be supplied fresh to the consumer, after preparation and packaging (WTO, 2015). According to the standard, bananas intended for cooking (plantains) or for industrial processing are excluded; and the dessert type varieties, from among the AAA Genome Groups, covered by the Standard are Dwarf Cavendish, Giant Cavendish, Lacatan, Poyo (Robusta), Williams, Americani, Valery, Arvis, Gros Michel, Highgate, Pink Fig, Green Pink Fig, and Ibota.

According to the same Commission, the provisions concerning minimum quality requirements stated are such that the bananas must be: whole (taking the finger as the reference); sound, produce affected by rotting or deterioration such as to make it unfit for consumption is excluded; clean, practically free of any visible foreign matter; practically free of pests affecting the general appearance of the produce; practically free of damage caused by pests; free of abnormal external moisture, excluding condensation following removal from cold storage, and bananas packed under modified atmosphere conditions; free of any foreign smell and/or taste; firm; free of damage caused by low temperatures; practically free of bruises; free of malformation or abnormal curvature of the fingers; with pistils removed; with the stalk intact, without bending, fungal damage or desiccation. The hands and clusters are supposed to include a sufficient portion of the crown of normal coloring, sound and free of fungal contamination; a cleanly cut crown, not beveled or torn, with no stalk fragments. The development and condition of the bananas are also supposed to reach the appropriate stage of physiological maturity corresponding to the particular characteristics of the variety; to withstand transport and handling; and to arrive in satisfactory condition at the place of destination in order to ripen satisfactorily.

Similarly, the provisions concerning presentation, uniformity and packaging are stated in such a way that bananas must be packed in such a way as to protect the produce properly. The materials used inside the package must be new, clean, and of a quality such as to avoid causing any external or internal damage to the produce. Bananas shall be packed in each container in compliance with the Recommended International Code of Practice for Packaging and Transport of Fresh Fruits and Vegetables (CAC/RCP 44-1995, Amd. 1-2004). Besides, the contents of each package are supposed to be uniform and contain only bananas of the same origin, variety, and quality.

2.6. Pre and Postharvest Factors Influencing Shelf-Life and Quality of Banana Fruits

Banana is affected by several constraints in both the abiotic and biotic categories all along the value chain. Asare-Kyei (2009) and Gustavsson *et al*. (2011) stated that postharvest losses are highest with crops like banana, of which postharvest quality is much dependent on climatic conditions, nature of the crop, different pre- and postharvest practices. Generally, the pre and postharvest constraints of banana can be viewed in light of the following factors.

2.6.1. Pre-harvest factors affecting shelf-life, postharvest quality and losses of banana

Diverse biotic and abiotic factors that occur prior to harvest are known to alter the quality (appearance, flavor, texture, etc) and shelflife of banana fruits. In a nut shell, these include genetics of the crop, growing environment, management practices, maturity at harvest and method of harvesting

2.6.1.1. Genetic factors

The quality of plant material is an important factor that controls the quality of the fruit (Hewett, 2004). According to this author, fruit shapes, sizes, colors, productivity levels, dry matter and taste attributes, as well as ripening times and rates and postharvest longevity may vary on the bases of genetic variations. Therefore, growers have to make appropriate decisions in selecting cultivars prior to planting; unless otherwise their choices are limited by availability of planting materials (sword and water suckers, maiden plants, corms, eye-buds, or plantlets).

2.6.1.2. Environmental conditions

Environmental conditions such as temperature, irrigation water, nutrition and light intensity also affect postharvest quality of banana (Kader, 2002; Hewett, 2004). Fore example, temperature influences uptake and metabolism of mineral nutrients, since that transpiration increases with higher temperature (Kader, 2002).

2.6.1.3. Management practices

As stated by Kader (2002) and Seleznyova *et al*. (2003), management practices such as type of planting material, irrigation, mulching, fertilization, weeding/cultivating, flower and fruits (propping stems with support poles, bunch spraying against pests and diseases, deflowering to increase the concentration of food nutrients for fruit development, debudding /debelling to channel food nutrients to the fruit bunch, bagging bunches to prevent insect pests from laying eggs, and ribboning/tagging to determine the exact stage of harvest maturity) and fertilization ultimately affect shelf-life and postharvest (physical and nutritional) quality of fruits. They also explained pests (fruit scarring beetles, thrips, mealy bugs, aphids, corm weevil, etc.) and diseases (Panama Disease or Fusarium Wilt, Bacterial Wilt, Sigatoka, Black Leaf Streak, Banana

Bunchy Top (BBT), etc.) as well as numerous physiological disorders associated with mineral deficiencies and overall plant tissue performance. For example, they stated that severe water stress results in increased sunburn of fruits; moderate water stress reduces fruit size while increasing total soluble solids and total acidity contents. On the other hand, they explained excess water supply to the plant results in cracking of fruits, increases susceptibility to physical damages, reduces fruit firmness, delays fruit maturity, and reduces total soluble solids content. Cultural practices such as pruning and thinning also determine the crop load and fruit size, which can influence nutritional quality of fruits; and the use of pesticides and growth regulators may also indirectly delay or accelerate fruit maturity.

2.6.1.4. Maturity at harvest

Harvest maturity determination has a very decisive impact on subsequent quality and postharvest life potential of fruits (Kader, 2002). Deciding when to harvest a banana fruit is often one of the most difficult decisions that a grower has to make. According to Reid (2002) and Crisosto et al. (2001), there are many different ways for determining fruit maturity or harvest maturity indices such as % of total soluble Solids to obtain optimal flavor, % dry matter in the fruit, fruit acid content to obtain optimal taste/flavour and total acceptability. Thus, it is likely that a combination of techniques need to be employed to decide the optimum time of harvest to allow long storage and shelf life while maintaining excellent eating quality. Eduardo (2012) stated that commercially bananas are harvested while mature green and transported to destination markets where they are ripened under controlled conditions in that fruits ripened on the plant often tend to split and have poor texture. But in most cases, the stage of maturity for banana harvest depends on the market for which the fruits are intended and is determined in terms of the marketable life required. One very often used criterion for harvesting banana fruits are age of the bunch after emergence from the pseudostem, finger size (finger length and diameter as measured by caliper grades) and finger fullness (angularity). In fact, at a given age, since the maturity of hands in a stem varies and those hands at the proximal end of the stem become more matured than those at the distal end, an estimate of maturity of the entire stem is assessed using the second hand from the proximal end.

2.6.1.5. Harvesting methods

Kader (2002) and Hewett (2004) stated that rough and improper harvesting methods and facilities can determine the extent of physical and mechanical (bruising, surface abrasions, cuts, etc.) injuries, which can consequently influence the direct physical quality attributes of fruits, accelerate loss of water and increase susceptibility to decay causing pathogens.

2.6.2. Postharvest factors influencing quality and shelf life of banana

Being perishable, banana fruits are highly prone to a number of postharvest problems. Various extents of qualitative and quantitative losses are often encountered as the produce goes through the supply chain up until it reaches the hands or dining tables of the ultimate consumers (Yahia, 2009; Gustavsson *et al*., 2011; Adeoye *et al*., 2013). The damages are often caused by various physical and mechanical damages, inappropriate handling environments and facilities, and pests and diseases. Such damages are operationally incurred during farm-gate preparation of fruits (washing, sorting, grading, packaging, loading, etc.), transporting, unloading at wholesale centers, storing, ripening, de-handing, distribution to retail centers and subsequent handlings or marketing systems. The major factors that impact the quality and shelf life of banana fruits under such chain of circumstances are outlined below.

2.6.2.1. Storage conditions (temperature, relative humidity, O_2, CO_2, etc.)

Keeping fruits within their optimal ranges of temperature and relative humidity is the most important factor in reducing the effects of respiration, transpiration and ethylene and thereby maintaining their quality and minimizing subsequent postharvest losses (Kader, 2002). Delays between harvesting and pre-cooling or processing can result in direct losses (due to water loss and decay) and indirect losses (losses in flavor and nutritional quality). Responses to atmospheric modification vary greatly among fruit development stages, and duration and exposure time to the prevailing atmospheric conditions and temperature.

2.6.2.2. Postharvest treatments applied to the commodity

These include cleaning (improve appearance and prevent primary inoculums) and sorting/grading (by color, size, level of defects, maturity/ripeness stage, etc.), waxing (provide protection against decay and excessive respiration, and improve appearance and acceptability), treatment with fungicides for decay control (e.g. due to Anthracnose caused by *Colletotrichum musae,* crown rot caused by both *Colletotrichum musae and Fusarium sp.,* and Cigar End Rot caused by either *Ventricillium theobromae* or *Trachysphaera fructigena*), fumigation for insect control, de-greening or exposure of fruits to ethylene and similar metabolic inducers for faster and more uniform ripening, extending green-life by applying anti-ethylene compounds such as 1-MCP, regular packing (to protect and create favorable impression to the produce), modified atmosphere packaging/storage (altering the normal composition of air surrounding the produce for increasing shelf-life and maintain quality by reducing the effects of respiration, transpiration and C_2H_4), etc. (Kader,2002).

2.7. Basic Physiological and Biochemical Changes in Harvested Banana Fruits

2.7.1. Changes in respiration and transpiration rates

Respiration is a process by which stored organic materials (carbohydrates, proteins, and fats) are broken down into simple end products with a release of energy (Irtwange, 2006). Oxygen is used in this process and carbon dioxide is produced. During the respiration process banana fruits tend to loss their stored food reserves. This normally leads them towards senescence as the reserves that provide energy will be exhausted. Fruits also tend to loss their flavor quality, especially sweetness during excessive respiration and senescence. The rate of deterioration is generally proportional to the respiration rate (Irtwange, 2006). Because banana is a climacteric fruit, it exhibits a respiratory peak during ripening process within a couple of days, with respiration rate of about 20 mg CO_2 Kg^{-1} h^{-1} at 20^oC at the beginning to about five times at the climacteric peak (Irtwange, 2006). According to this author, increase in respiration rate during fruit ripening is also accompanied with a considerable level of water loss through transpiration. The loss of water and other respiratory substrate during ripening or as the storage period extends, ultimately results in a decrease in shelflife and overall physicochemical quality attributes of the banana fruits (Kays, 1999; Irtwange, 2006).

Because harvested banana fruits are still living biological systems, the respiration rate is an important indicator of their scale of metabolic process (Wills *et al*., 2007). According to these authors, respiration is basically taking place to supply energy for catabolic processes occurring over the postharvest life of the fruits, with little apart of the energy being lost as heat. Climacteric fruit such as banana and apples are generally characterised by a typical respiratory peak during ripening. Depending on the availability of oxygen, respiration can occur under aerobic or anaerobic conditions (Wills *et al*., 2007). In the postharvest handling of fresh fruits, maintaining aerobic respiration (consists of the processes of glycolysis and tricarboxylic acid (TCA) cycle that involve the release of normal CO_2) is the ultimate goal, since anaerobic respiration could produce off-flavours and overall tissue damage (Saltveit, 2004; Wills *et al*., 2007). The main substrates involved in aerobic respiration of harvested fruits are sugars and organic acids. The subsequent depletion in these compounds leads to changes in physicochemical quality attributes (i.e. decrease in fruit weight, firmness, green color, drymatter, pH, starch content and increase in TSS, TA, TSS:TA ratio, and moisture content) as well as changes in overall consumer acceptability (taste, flavor, aroma, texture, mouth-feel, etc).

According to Irtwange (2006), postharvest transpiration is also defined as being the evaporation of water from the fruit tissues. Water loss is a very important cause of produce deterioration with severe consequences in loss of marketable weight and overall fruit appearance (shriveling). Eventually, transpiration is a result of morphological and anatomical characteristics of the fruits, surface injuries and maturity stage, temperature, relative humidity, air circulation and atmospheric pressure (Irtwange, 2006). The magnitude of both respiration and transpiration depends on temperature, relative humidity and air-composition around the produce. Hence, as physical processes, both respiration and transpiration can be controlled postharvest using different techniques such applying waxes; using plastic films as barriers to gas exchange with the external atmosphere and by modifying the atmosphere surrounding the produce (reduces use of respiration substrates such as organic acids and sugars); and by manipulating the levels of relative humidity, temperature, air circulation and ethylene concentration (Irtwange, 2006; Ding *et al*., 2009; Hailu *et al*., 2013).

2.7.2. Changes in ethylene biosynthesis and action

The increase in ethylene production rate in banana fruits normally begins at the point of harvest concurrently with increase in the level of maturity, physical injuries, disease incidence, temperatures and water stress (Pesis, 2004). Being a climacteric crop, exposure of banana fruits to ethylene advances the onset of an irreversible rise in respiration rate and rapid ripening. Ethylene production is normally followed by a rise in the rate of respiration. As the rate of ethylene production declines, the rate of respiration correspondingly reaches its maximum at around 125 mg CO_2 Kg^{-1} and then declines slightly (Hailu *et al*., 2013; Pesis, 2004). Thus under commercial systems, various techniques are employed to reduce both the production and action of ethylene and by so doing extend the shelflife of banana fruits while maintain their fresh quality. Such techniques include the application of controlled and modified atmospheric storage/packaging (reduced O_2 and elevated CO_2 levels), storage at low temperatures (13^{o}C-14^{o}C), using ethylene scrubbers, introducing fresh air into storage rooms, and application of some compounds such as aminoethoxyvinylglycine (AVG) as inhibitor of ethylene synthesis and 1-Methylcyclopropene (1-MCP) as inhibitor of ethylene action, and potassium permanganate ($KMnO_4$) as an oxidizing agent (Kader, 2002; Pesis, 2004; Irtwange, 2006; Javasheela *et al*., 2015).

The increase in the rate of respiration of banana fruits over the postharvest life is also considered as a consequence of the increased rate of ethylene production (Tromp, 2005). Ethylene, as a natural plant hormone, is known to influence many physiological behaviors of banana fruits including their ripening process and shelflife (Blankenship, 2003). Likewise, as in the case of respiration, the effect of ethylene on postharvest life and quality of banana fruits is known to depend on the storage atmosphere (temperature, relative humidity, air circulation, etc.) and application of certain postharvest treatments such as 1-MCP (Blankenship, 2003).

In order to induce the many biochemical changes associated with ripening (colour change from green to yellow, aroma development, softening, increased respiration etc.) and to stimulate its ethylene biosynthesis, ethylene needs to bind itself to specific ethylene binding sites or receptors (Watkins *et al*., 2000; Wills *et al*., 2007). However, the binding of ethylene to the receptor sites is known to be reversible and so different postharvest strategies such as low temperature storage, modified atmosphere packaging (MAP), and treatment of fruits with various ethylene antagonist compounds like 1-MCP are employed (Watkins, 2000; Wills *et al*., 2007). As such, traders are able to extend the shelf life of banana fruits by minimizing the rate of respiration and transpiration as well as the synthesis and action of ethylene (Watkins, 2002; Wills *et al*., 2007).

2.8. Techniques of Ripening Banana Fruits

As stated by Brady (1987) and Dadzie *et al*. (1997), the ripening of banana fruits is a very complex system and is characterized by a series of biochemical, physiological and structural changes, many of them probably occurring independently of each other. It is the process by which fruits attain their desirable flavour, quality, colour, palatable nature and other textural properties. Ripening is associated with change in composition i.e. conversion of starch to sugar. On the basis of ripening behavior, fruits are classified as climacteric and non-climacteric fruits. Climacteric fruits (mango, banana, papaya, guava, fig, apple, passion fruit, apricot, plum, pear, etc.) are defined as fruits that enter 'climacteric phase' after harvest i.e. they continue to ripen. During the ripening process the fruits emit ethylene along with increased rate of respiration. Non-Climacteric fruits (citrus fruits, grapes, pomegranate, litchi, strawberry, etc.) on the other hand, once harvested do not ripen further. Nonclimacteric fruits produce very small amount of ethylene and do not respond to ethylene treatment. There is no characteristic increased rate of respiration or production of carbon dioxide. In order to improve external skin colour and market acceptance, citrus like orange, lemon, can be treated with ethylene, as a de-greening agent (Dadzie *et al*. (1997).

Banana, like other climacteric fruits, is harvested in a mature but unripe condition, and subsequently allowed to ripen further. Because, under natural conditions, banana ripens slowly and in most cases unevenly, resulting in high weight loss, characteristically unattractive color and desiccation (ICAR, 2009; Eduardo, 2012).

The lack of simpler, rapid and affordable methods for fast and uniform ripening of banana fruits has been and still is posing several problems across many of the banana growing developing countries (ICAR, 2009). Although there are several banana ripening technologies employed in different parts of the world (primitive, traditional and modern or pressure systems), almost all of them are known to come with their own merits and demerits (ICAR, 2009). Fore example, in Southeast Asian countries, Calcium Carbide (CaC_2), which breaks down to form acetylene and known to produce the same effect as ethylene at high concentrations, is widely used (ICAR, 2009). The system is used by placing about half ounce of calcium carbide packets through the banana piles, which are covered with a tarpaulin to generate high humidity and activate the carbide. However, the system being increasingly banned, including in those countries, owing to its extremely hazardous effect to the human body (Mahmood *et al.*, 2013).

In some places, spraying or dipping of fruits in ethrel (ethephon or 2-chloro ethyl phosphonic acid), which breaks down to form ethylene, is employed for enhancing ripening, but it is known to be a cumbersome process, at times causing problems when the commercially available ethrel is mixed up with chemical impurities (ICAR, 2009).To overcome this, ethylene gas has been commercially used in modern ripening chambers. Although this is known to be the safest and worldwide accepted method, it is also not an economically viable option for farmers and small traders; and thus not widely employed in most developing countries (ICAR, 2009).In some countries including Ethiopia; banana ripening is commercially performed using kerosene smokes within air-tightly sealed chambers. However, this system is also known to be liable for lower consumer attraction owing to the resultant burnt scars, bruises, microbial infections, poor appearances on the peel, and contamination of the natural aroma of the fruits with the smoke (Sarananda,1998). Exposure of bananas to temperatures higher than those in the ripening range (20º- 25ºC) are also employed in some places, but these are also known to hasten softening and decay, weaken the neck, and the peel will remain green and cause splitting of the peel and poor development of color (Thompson *et al*., 1982). Conversely, uneven ripening can also be caused by low temperatures and insufficient ethylene (Robinson, 1996; Turner, 1997).

As reported by (ICAR, 2009), the only simple, harmless and economical alternative method employed in many places for enhancing ripening is exposing the banana fruits to ethrel generated ethylene in closed chambers such as plastic tents. The technique is employed by adding small quantity of alkali (often sodium hydroxide) to a calculated quantity of ethrel solution to release ethylene gas, and fruits are exposed to liberated gas in an air-tight portable plastic tent. In this method, fruits are placed inside ventilated plastic crates and placed inside the air-tight chambers of known volume. After 18-24 hours of exposure, fruits are taken out for completion of their ripening process at room temperature. Using such technique, banana bunches/hands exposed to 100 -1500 ppm ethyelene generated from 10 ml of ethrel solution and 2 gram of sodium hydroxide pellets and mixed in five liters of water within a wide mouthed vessel could ripen in

4-6 days when treated in air-tight chambers for 12-24 hours at ambient or room temperature (ICAR, 2009). According to this author, this method of using diluted ethylene gas mixtures is also known to be safer than using pure ethylene, which is explosive and flammable at concentrations of 3% or higher.

2.9. Use of 1-MCP as a pre-storage treatment to extend the shelf-life of banana fruits

Pre-storage treatments are treatments that are generally applied to banana fruits after harvest to enhance storage life, reduce postharvest losses, control ripening and senescence, and retain quality. Some of them like benomyl, Aluminium sulphate, chlorine and some essential oils like citral and lemon grass oil are disinfectants and those like aminoethoxyvinyvinylglycine (AVG), Potassium permanganate (KMnO4) and 1-Methylcyclopropene (1-MCP) are compounds that generally act as ethylene inhibitors (Kader, 2002; Pesis, 2004; Irtwange, 2006; Javasheela *et al*., 2015).

However, while aminoethoxyvinylglycine (AVG) and potassium permanganate ($KMnO_4$) are respectively employed as only inhibitors of ethylene synthesis and as an oxidizing agent to reduce ethyelene concentration within the banana packaging materials, 1-Methylcyclopropene (1-MCP) as a novel and highly volatile gas is known to play an effective double role both to inhibit its synthesis at a receptor level and subsequent action (Kader, 2002; Pesis, 2004; Irtwange, 2006; Javasheela *et al*., 2015). Besides, while it is structurally related to the natural plant hormone ethylene (with molecular formula of C_4H_6 vs. C_2H_4 to ethylene), 1-MCP is considered ergonomically as odorless, nontoxic and the safest product for all actors involved across the banana supply chain (farmers, marketers, ripeners, packinghouse and storage operators and consumers) and the environment at large (Blankenship, 2003; Watkins, 2006; Heyn, 2009) that leaves no detectable residue in treated fruits.

As reported by Daly *et al*. (2000) and Sisler *et al*. (2003), 1-MCP is a gaseous cyclopropene or cycloalkene derivative, with a molecular weight of 54.09 at standard temperature and pressure. It is commonly used commercially to slow down the ripening of fruits and maintain the freshness of cut flowers without leaving any detectable residues. The mechanism of action of 1-MCP involves its tight binding to the ethylene receptors in plants or fruits, thereby blocking the effects of ethylene. In other words, when 1-MCP molecules sit on ethylene receptor sites, they bind the receptors sites and do not allow the receptor to "unlock" like the ethylene molecule does (Blankenship, 2003; Trivedi, 2012). Therefore, no signal can be sent for a chemical reaction, which in turn delays the ripening process. But as mentioned earlier, ethylene and receptor site formation are a continuous process, and 1-MCP does not bind the receptor site permanently. So, eventually new receptor sites can be formed and ethylene can regain its sensitivity for them, once the entire available 1-MCP molecule has been used up to block available receptor sites (Blankenship, 2003; Trivedi, 2012). In line with this concept, a number of studies have been reported on the ability of 1-MCP to extend the shelf life of banana fruits, by delaying the ripening process, with wide range of concentrations ranging from 0.1 nl L^{-1} to 1000 nl L^{-1}, as well as different treatment durations ranging from 1 to 72 hours (Pelayo *et al*., 2003; Jiang *et al*., 2004; Nanthachai *et al*., 2007; Trivedi, 2012).

Commercially, I-MCP is marketed either under the brand name of "EthylBloc" for use on ornamental plants or under the brand name of "SmartFresh" to extend the shelf life and maintain the quality of fruits and vegetables by preventing or delaying the natural ripening process. The SmartFresh powder is formulated along with other inert materials usually carrying 0.14% 1-MCP as active ingredient, which is mixed with a specific amount of pure water or other buffer solutions to release it in the vapor form to the air surrounding the produce within the air-tight treatment structures (Daly *et al*., 2000; Sisler *et al*., 2003). Because it is a highly volatile gas with a boiling point of about 12 ^{o}C, commercially it is often available in an air-tightly sealed encapsulated form. It is prepared to release its gas molecules simply by dissolving it in appropriate amount of buffer solvent such as KOH or as mentioned above in pure distilled water (Mir *et. al*., 2004; Watkins, 2006). More recently, 1-MCP is also being developed as a new crop protection technique to protect crops from moderate heat and drought conditions by spraying on to plants at their growth stages (Daly *et al*., 2000; Sisler *et al*., 2003).

CHAPTER 3: ASSESSMENT OF BANANA PRODUCTION AND MARKETING IN ETHIOPIA

Abstract

The study was conducted to assess and identify the factors that influence the production and marketing performance of banana in Ethiopia. Multi-stage purposive and random sampling techniques were alternatively employed at different stages to collect the necessary primary data. Secondary data was also collected from written documents and focus group discussions (stakeholders) across the survey areas. The data for smallholder banana growers were collected from 3 major banana producing zones, 5 districts and 10 farmer villages. The data for large-scale commercial banana producers was collected from a wider part of the country covering 14 farms from 3 regional states. The marketing data encompassed almost all the major market outlets in Ethiopia. As such a total of 150 small-scale and 14 large-scale growers, 59 wholesalers/ripeners, 53 retailers and 53 consumers were interviewed using structured and semi-structured questionnaires. Comparative econometrics and descriptive results as well as multiple linear regression analysis have been employed to determine and quantify the impact of the explanatory variables or factors affecting the yield performance of banana in the study areas. Results indicate that different household and farm characteristics such as age, household size and experience in banana production, area of land allocated and method of banana production (irrigated or rainfed), spacing and type of planting material used, household head (male or female-headed), extension service, membership of farmer cooperatives/unions, etc. affect the yield of banana in the study areas. About 13 marketing channels were identified across the banana supply chain in Ethiopia. Gross Marketing Margins (GMMs) were computed not merely to indicate pure profit margin without considering marketing costs but to point out the possible added transaction values for product ownership and income generation. Results of channels that terminate within domestic markets show GMMs ranging 29.2%-43.8% for small-scale growers, 33.3%-45.8% for large-scale commercial growers, 16.7%-43.8% for cooperatives/unions, 4.8%-12.5% for farm-gate collectors, 25%-37.5% for wholesalers/ripeners, and 29.17%-50% for retailers. Results generally indicate that eventhough the country has vast potential for banana production, the supply chain is facing several limitations and constraints that include high variability in crop management practices and yield, and highly deregulated marketing practices that result in excessively high price and marketing margin disparities across the numerous channels. These points out the need for increased research and extension services, and improvement in marketing logistics and channel management.

Keywords: *Banana; determinants; marketing margin; supply-chain; yield*

3.4. Introduction

Dessert banana and plantain *(Musa spp.)* are the fourth most important staple food crops in the world after rice, wheat and maize (Salvador *et al*., 2007). Dessert banana in particular is a commercially important crop in the global trade, both by volume and value. In 2010, world commerce in banana was valued at US 8.05 billion and the total world production of banana was about 106,541,709.00 tons. For many African, Asian and Latin American countries, banana is as well one of the most important crops for foreign exchange earnings (FAOSTAT, 2012).

Dessert banana is also the major fruit crop that is most widely grown and consumed in Ethiopia. It is cultivated in several parts where the growing conditions are favorable. Especially in the south and southwestern parts of the country, it is of great socioeconomic importance contributing significantly to the overall well being of the rural communities including food security, income generation and job creation. Banana in Ethiopia covers about 59.64% (53,956.16 hectares) of the total fruit area, about 68.00% (478,251.04 tones) of the total fruits produced, and about 38.30% (2,574,035) of the total fruit producing farmers (CSA, 2014). On the other hand, about 68.72% (37,076.85 hectares) hectares of land covered by banana, about 77.53% (370,784.17 tones) of the banana produced and 22.38% (1,504,207) of the banana producers in Ethiopia are found in the Southern Nations Nationalities and Peoples' National Regional State- SNNPRS (CSA, 2014). Gamo-Gofa, Bench-Maji and Sheka zones are among the major banana producing zones of the SNNPRS, of which Gamo-Gofa zone alone covers over 70% of the total banana marketed across the major market places in Ethiopia (CFC, 2004). Depending on the season, 60 to 90 truckloads of banana bunches, each truck carrying 5-9 tons (ISUZU truck load capacity = 5-5.5 tons and FSR truck load capacity = 8-9 tons), are sent every day to all market places in Ethiopia. In 2013 alone, about EBirr 7,120,400.00 of domestic revenue was obtained from about 55,946 tons of banana distributed only from the Aba-Mich Zuria and Mirab-Abaya districts of the Gamo-Gofa zone (Table 9.).

The major commercial cultivars grown by small-scale growers across the survey areas are Dwarf Cavendish, Giant Cavendish, and Poyo, with Williams, Butuzua and Grand Naine recently coming into picture in Gamo-Gofa zone and across the large-scale commercial farms of Ethiopia.

The rest are less popular land races grown to a very limited extent in certain localities across the country (Table 6 and Annex Figure 9.2.3.).

Despite the above stated facts and the concerted effort being made by the government of Ethiopia to promote and diversify its agricultural outputs as well as exports at large, the attention given to banana especially in terms of research, extension services, investment endeavors and overall supply-chain management has been very limited. In most parts of the country, its production has yet been limited to backyard and small-scale productions with the produce largely supplied to local markets (Annex Figure 9.2.1.). Large scale production in Ethiopia (Annex Figure 9.2.2.) covers only 0.19 % (1,910.97 hectares) of the total area covered by banana and 0.22% (17, 924.59 tones) of the total banana produced in Ethiopia (CSA, 2014).

Except some haphazard applications of farmyard manure and household leftovers when grown at back yard, small-scale growers in Ethiopia generally do not apply fertilizers to bananas. Instead they leave the slashed weeds and chopped banana leaves around the clamps which to some extent help maintain the fertility of the soil. While bananas in Gamo-Gofa zone are grown under irrigated condition (Table 13; Table 14; Annex Table 9.1.1.1.1. and Annex Figure 9.2.4.), the production in Bench-Maji and Sheka zones is entirely rainfed.

Besides, other than those organized into farmer cooperatives/unions (Annex Table 9.1.1.2.), most small-scale growers do not apply the right agronomic practices to banana such as using the right type of sword suckers, maintaining appropriate spacing and sucker management, and regular control of weeds and soil moisture management.

As stated by Tekle *et al*. (2014), pests snd disease problems as well as lack of improved varieties is as well one of the critical factors that affect the production and productivity of banana in Ethiopia (Annex Figure 9.2.5.). As a result, the productivity of banana in most places in Ethiopia is 5-8.95 tons/ha (CSA, 2014), which is far below the world average of 15.8 tons/ha (FAOSTAT, 2012). A summary report by Nicholas *et al*. (2013), based on 2012 baseline survey results of the Agricultural Transformation Agency of Ethiopia (ATA), also indicate that the average yield and revenue obtained from banana sales by banana growing households in Ethiopia is only 8,759 kg/ha and 21.3 Birr/year respectively (Annex Table 9.1.1.3.).

Various studies using multiple linear regression have identified that the yield of several crops including banana is influenced by various determinants (factors) such as inputs of production, agronomic and management practices, and producer and farm characteristics (Javed *et al*., 2001; Ahmad *et al*., 2005; Bakhsh *et al*., 2005; Bathan *et al*., 2010). However, in Ethiopia, no empirical data is so far available in this respect whereby the explanatory variables that influence the yield of banana could be identified and quantified.

Cognizant of this, the present study was similarly undertaken to assess and identify the factors determining the yield and marketing performance of banana in Ethiopia with a subsequent aim to provide relevant information that help reinforce concomitant interventions into the future.

3.5. Research Methodology

3.5.1. Regional and geographical distribution of the survey areas

The banana production sites and market places covered through the survey are shown in Figure 1 below.

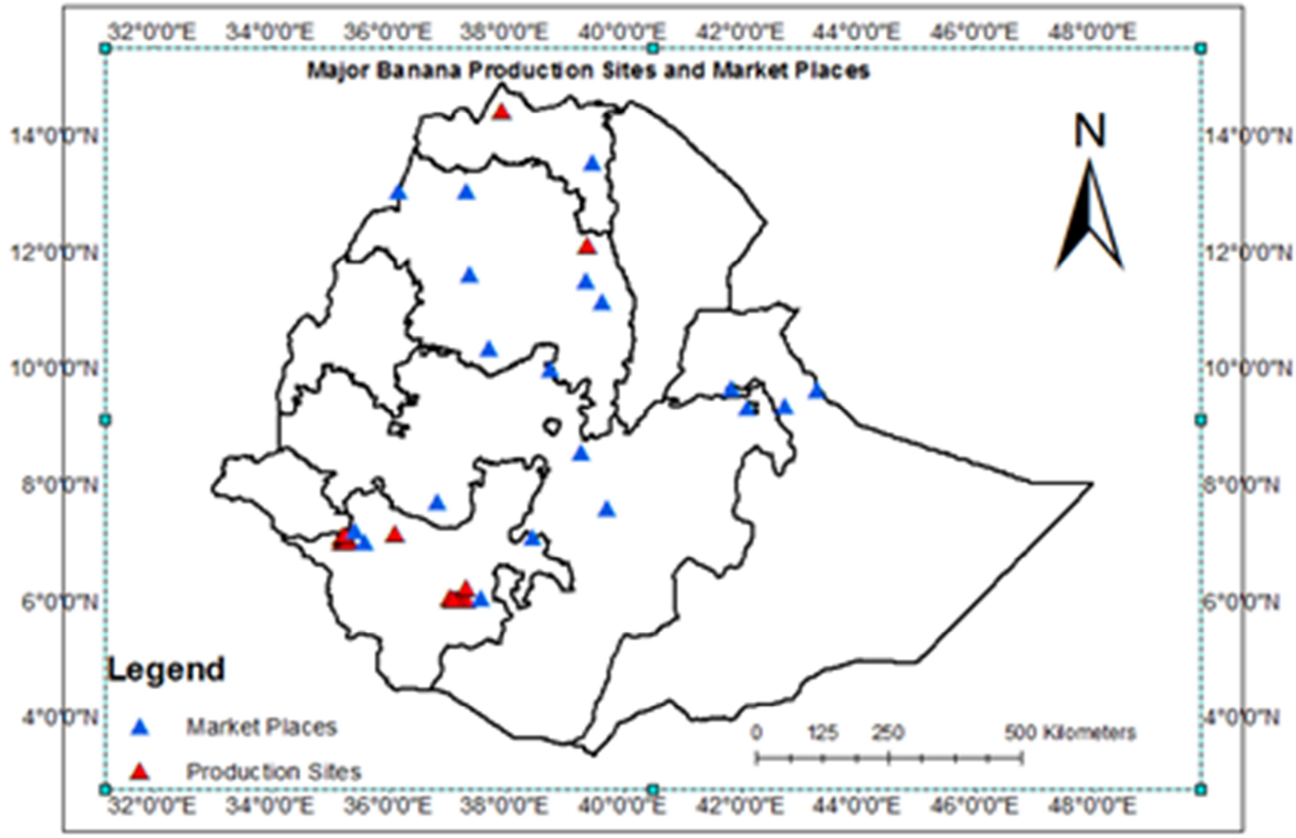

Figure 1. Regional and geographical distribution banana production areas and market places covered by the survey, 2014/15

3.5.2. Rationale and description of the banana production areas addressed in the study

The survey on smallholder banana producers was solely conducted in the Southern Nations Nationalities and Peoples' Regional State (SNNPR) of Ethiopia covering 3 zones (Gamo-Gofa, Bench-Maji and Sheka), 5 woredas (districts) and 10 kebeles (farmer villages). It is an important regional state where the bulk (77.53%) of the banana marketed and consumed in Ethiopia comes from (CSA 2014). Almost all the banana commercially sold in all the major towns of Ethiopia, including Addis Ababa, is produced in this regional state, with Gamo-Gofa comprising over 65% of the market share, Bench-Maji 10% and Sheka 5% (CFC, 2004). Only the balance comes from other pocket areas of the country that are less known for banana production (CFC, 2004). Banana in those areas is a major component of livelihood strategies, which constitutes an important food security and household source of income for many farmers (CFC, 2004). Thus, in those zones, a total of five districts, 10 villages, and 150 farm households were considered for the survey work at producers' level (Table 7 and Table 13).

As shown under Table 7. ; Table 14 and Figure 1, the study on the large-scale commercial production of banana was also carried out on a wider part of the country covering 14 farms from 3 national regional states (SNNPR, Tigray and Amhara).

Table 7. Banana producers and other stakeholders consulted across the survey areas

Zone	Woreda (District)	Kebele (Village)	No. of small-scale farmer households		No. of Large-scale farms	Other stakeholders
			MH	FH		
Gamo-Gofa	Arba-Mich Zuria	Sile-Kanchama	11	4	8	-Zonal, woreda & kebele agric. Offices -Mirab-Abaya & Arba-Minch Zuria Woreda Revenue Authority Branch Offices -NGOs (Vita, SNV& LIVES) -AMARC -GFVFMCU -Respective kebele farmer cooperatives
		Ocholo-Lante	12	3		
	Mirab-Abaya	Omo-Lante	9	6	1	
		Ankober	5	10		
Bench-Maji	North-Bench	Fakatin	9	6	1*	-Zone, woreda & kebele admin. & agric. Offices - *BCESC
		Gorit-ena-Mag	12	3		
	South-Bench	Kitte	10	5		
		Fanika	11	4		
Sheka	Yeki	Addis Birhan	11	4	1*	-TARC -*TGCESC -Woreda & kebele Agric. offices
		Fide	10	5		
Keffa	Gimbo	-	-	-	1*	-*Gojeb Agri. Dev't Ent.
NWTigray	Tahitay-Adiabo	-	-	-	1*	-*Tekeze Fruit Growers Ass.
North-Wollo	Raya-Kobo	-	-	-	1*	-*Kobo-Girana Banana Farm
6	8	10	100	50	14	-

Where:

MH=male-headed household; FH=Female-headed household; TARC=Tepi Agric. Research Center; AMARC=Arba-Minch Agricultural Research Center; GFVFMCU= Gamo-Gofa Farmers Vegetable and Fruit Marketing Cooperative Union PLC; NGOs=Non-government Organizations (Vita, SNV &LIVES); TGCESC= Tepi Green Coffee Estate Share Company; BCESC= Bebeka Coffee Estate Share Company.

3.5.3. Description of the banana market places covered and supply chain actors consulted across the survey areas

As shown in Table 8 and Table 10, the market level study was carried out across 19 major regional and central towns or market outlets in Ethiopia. They are normally the centers where the traders (wholesalers, retailers and exporters), market regulatory institutions as well as the bulk of the ultimate consumers are found.

Table 8. Banana traders and other stakeholders consulted across the survey areas

Market outlets	Banana Market-Chain Actors					Other stakeholders
	No. of farmer cooperatives/unions	No. of licensed farm gate collectors (forwarders)	No. of wholesalers /Ripeners	No. of retailers	No. of consumers	
Arba-Minch	5	12	1*	3	3	Gamo-Gofa Zone Customs & Revenue Branch Office
Hawassa	-	-	5**	3	3	-
Addis Ababa	-	-	13***	6	6	-Ethiopian Customs & Revenue Authority -Central Statistics Agency
Adama	-	-	3	3	3	-
Assela	-	-	1	2	2	-
Harar	-	-	3	3	3	-
Dire-Dawa	-	-	2	3	3	Dire-Dawa Customs & Revenue Office
Jigjiga	-	-	3	3	3	Jigjiga Customs & Revenue Office
Tog-Wajaale	-	-	1	2	2	-
Mekelle	1	-	4****	3	3	-
Woldiya	-	-	6	2	2	-
Dessie	-	-	5	3	3	-
Debre-Markos	-	-	2	2	2	-
Bahir-Dar	-	-	3	3	3	-
Gondor	-	-	2	3	3	-
Metema Yohannes	-	-	-	2	2	Metema Woreda& Metema-Yohannes Kebele Agric.Offices
Jimma	-	-	5		3	-
Mizan	-	-	-	2	2	-
Tepi	-	-	-	2	2	-
19	6	12	59	53	53	-

Source: own survey result, 2014/15

*Refers to the Gamo-Gofa Farmers Vegetable and Fruit Marketing Cooperative Union PLC (GFVFMCU)

**Includes the Ocholo Lante Kebele (Village) Famers'Cooperative in Gamo-Gofa zone

***Includes ETFRUIT (public commercial enterprise)

****Includes the Shiraro-Tekeze Banana Growers Association in Tigray Regional State

In this respect, the study was started at farm gate level and continued all the way to the end of the banana supply chain in Ethiopia. The study adopted a number of alternative approaches for generating both quantitative and qualitative data. It included extensive interviews and discussions with the direct market actors as well as private and public enterprises such as research, extension, marketing and regulatory institutions. A systematic random sampling was employed and accordingly a total of 12 licensed farm gate collectors, 6 farmer cooperatives/unions, 59 wholesalers/ripeners, 53 retailers, 53 final consumers and 4 market regulatory institutions (i.e. Customs and Revenue Branch Offices) were considered for the study (Table 8).

3.5.4. Description of the banana market places covered and supply chain actors consulted across the survey areas

Both quantitative and qualitative data collection methods were employed using a cross sectional type of research approach in the primary and secondary information collection process. The primary data was collected through interviews using both structured (close ended) and semi-structured (qualiatative or open-ended) questionnaires (**Annex Tables 9.1.4.).** The close ended questions were designed as list or select any appropriate/correct answer and they were coded. The open ended questions were designed in such a way to allowing the respondents to freely express their ideas. In addition to the questionnaires, focus group discussions were carried out with all banana supply chain actors (producers, traders, farmer cooperatives/unions, researchers, extension workers and regulatory bodies). The secondary data was acquired from published and unpublished reports of different levels of actors such as line national, zonal, district and village level agricultural extension, research, marketing, cooperative, customs and revenue, statistics, and NGO offices as well as internet (website) search based sources (**General Annex Section 4: Survey Itinerary).**

3.5.5. Sampling technique

A multi-stage purposive and random sampling technique was alteranatively employed to collect all the necessary primary data. Initially, five major banana producer districts were purposively selected jointly with the respective zonal agricultural offices on the basis of volume of banana production. Then, 10 major banana producer farmer villages (2 villages/districts) were similarly selected purposively jointly with the respective district agricultural offices. Finally15 respondent households were randomly selected for the interview from each village from the total list of banana producer households provided by each of the village level agriculture offices.

Development Agents (DAs) of the respective study villages were largely used as enumerators to work alongside the researcher. They were given about half a day briefing by the researcher on the contents of the questionnaires and way of handling of the interview. The market related data were collected randomly from the other banana supply chain actors across the country (farm-gate collectors, wholesalers/ripeners, retailers, consumers and other stakeholders) using other separate questionnaires to generate primary data. As such a total of 150 small-scale farmer households, 14 large-scale (commercial) growers, 59 wholesalers/ripeners, 53 retailers and 53 consumers were randomly selected based on size proportional probability and interviewed in the primary data collection process using the respective questionnaires (Table 7 and Table 8).

3.5.6. Method of data analysis

The SPSS (Statistical Package for Social Sciences) software was used for data entry and analysis. A descriptive statistics was used that include parameters such as sum, mean, percentage, etc. In addition, mean comparison techniques such as Analysis of Variance (ANOVA) and independent sample–t test were employed to compare the differences in banana production among locations or handling practices.

In order to identify the determinants of the banana productivity, the following multiple linear regression model was used for identifying the determinants of yield. It is applied using the amount of yield as dependent variable and other explanatory variables such as the type of agronomic practices and marketing systems as independent variables.

$$Y1 = \beta 0 + \beta 1\ F1 + \beta 2\ F2 + \beta 3\ F3 + \beta 4\ F4 + \beta 5\ F5 + \beta 6\ F6 + \beta 7\ F7 + \beta 8\ F8 + \varepsilon$$

Where:

Y1= is the amount of yield (t/ha); F1= the topography of the land used for banana production; F2=Age of the household head (HHH); F3= Size of the household; F4=Household experience in banana production; F5= Number of suckers allowed per hill (plant); F6=Type of planting material (sucker) used for planting; F7= Use of spacing for banana production; F8= Area (size) of land allocated by the household for banana production

3.6. Results and Discussion

3.6.1. Performance of the supply chain actors, marketing channels and margin analysis

Under this section, the banana supply chain actors and their functions, results of gross market margin analysis, and other determinant factors of banana production and marketing in Ethiopia are presented to evaluate the performance of the banana industry in the study areas.

3.6.2. Banana supply chain in Ethiopia

Both small-scale and large-scale banana producers in Ethiopia follow similar marketing channels as shown in the banana supply chain chart below (Figure 2.).

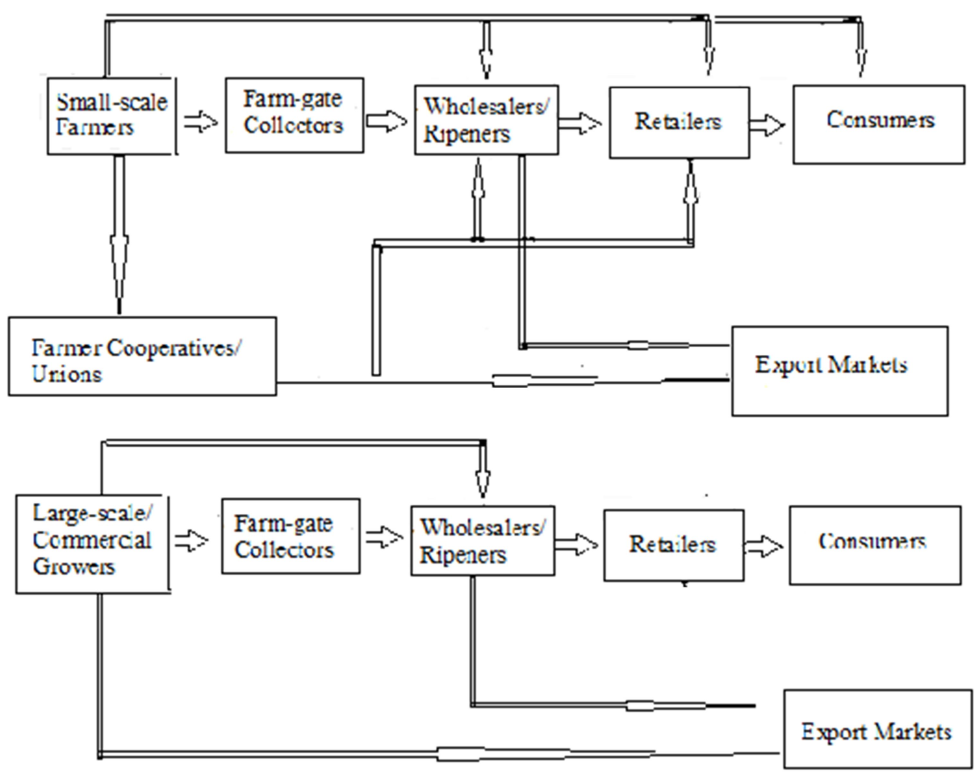

Figure 2. Supply Chain of Banana in Ethiopia

3.6.3. Performance of the various segments across the banana supply chain

As illustrated in Figure 2, the banana supply chain in Ethiopia comprises the following major segments.

Producers

These are both small-scale farmers and large-scale commercial growers involved in banana production (Table 13 and Table 14). As stated earlier, both small and large-scale growers in Gamo Gofa zone are the major banana producers in Ethiopia. Depending on the season, 60 to 90 truckloads of banana bunches, each truck carrying 5-9 tons (ISUZU trucks 5-5.5 tons and FSR trucks 8-9 tons), are dispatched every day from this zone to all market places in Ethiopia. In 2013 alone, about EBirr 7,120,400.00 of domestic revenue was obtained from about 55946 tons of banana distributed only from the Aba-Mich Zuria and Mirab-Abaya districts of the Gamo-Gofa zone (Table 9.).

Table 9. Banana distributed from Arba-Minch Zuria and Mirab-Abaya districtsand revenue (Birr) obtained, January 1, 2013-Dec. 30, 2013

	Destination	No.of ISUZU truck loads		Revenue obtained (Birr)***	
		Arba-Minch Zuria*	Mirab-Abaya**	Arba-Minch Zuria***	Mirab-Abaya**
1	Addis Ababa	6227	-	4358900	-
2	Mekelle	514	-	359800	-
3	Gondor	291	-	203700	-
4	Tog-Wajaale	143	-	100100	-
5	Harar/D/Dawa	77	-	53900	-
6	Hawassa	85	-	59500	-
7	Woldiya	74	-	51800	-
8	Dessie	72	-	50400	-
9	Adama	43	-	30100	-
10	Jimma	23	-	16100	-
11	Korem	22	-	15400	-
12	B/Dar	17	-	11900	-
13	Moyale	14	-	9800	-
14	Jigjiga	8	-	5600	-
15	Adigrat	6	-	4200	-
16	Maichew	6	-	4200	-
17	Bale-Robe	4	-	2800	-
18	Shashemene	2	-	1400	-
19	Hossana	2	-	1400	-
	Sub-Total	7639	2533	5,347,300.00	1,773,100.00
Total		10172		7,120,400.00	

Source:
*Arba-Minch Zuria District Agricultural Product Marketing Office, January 2014;
**Mirab-Abaya District Customs and Revenue Branch Offices, January 2014
***Arba-Minch Zuria District Customs and Revenue Branch Offices, January 2014
Where:

- One ISUZU load= 5 to 5.5 tons (revenue rate=Birr 700.00/ISUZU for traders & 500.00/ISUZU for cooperatives)
- One FSR load of banana= 8 to 9 tons (revenue rate=Birr 900.00/FSR for traders & 700.00/ISUZU for cooperatives)

The role of small-scale farmers is by and large limited to production and they have no much control over the price that they receive from their produce. After harvest, they sell their banana to either local licensed farm-gate collectors, farmer cooperatives/unions when any, directly to distant market traders who purchase the banana at farm-gates, or to a limited extent to local market retailers and roadside vendors (Annex Figures 9.2.6, 9.2.7, 9.2.8. and 9.2.13.) Often times when farmers sell their banana directly to distant market traders or farm-gate collectors, they are exposed to varied malpractices such as fraud weighing balances and underestimated guess purchases when the transaction is done on the basis of negotiated quantities in piled bunches. Farmers who are not members of farmer cooperatives/unions are often victims of such market misconducts.

When bananas are sold to local licensed farm-gate collectors and farmer cooperatives/unions, they are forwarded or transported piled in lose bunches without any package to major urban centers by open or non-refrigerated ISUZU or FSR trucks (Annex Figures 9.2.6 and 9.2.9). They are then sold directly or on contractual agreement basis to wholesalers across the major regional and central towns of the country who at the same time do the ripening operation through the traditional kerosene smoking system (Annex Figures 9.2.10, 9.2.11 and 9.2.12). The wholesalers then distribute the ripened banana to close or distant retailers (supermarkets, green grocers, street or roadside vendors, traditional open market retailers, etc.) in their respective localities. Retailers often purchase green ripe bananas from wholesalers and keep them till they develop the ultimate yellow color before they sell them to the final consumers (Annex Figures 9.2.13 and 9.2.14)

Farmer cooperatives/unions

These are a group of village level farmers formally organized into farmer cooperatives or unions in order to market their banana and access or purchase inputs. The majority of farmers in the banana growing villages in Gamo-Gofa zone are organized into village level farmer cooperatives, with the cooperatives further organized as members of the Gamo-Gofa Farmers Vegetable and Fruit Marketing Cooperative Union PLC. This union is the only cooperatives' union so far engaged in banana business in Ethiopia. It is a strong union that, on behalf of its member cooperatives, at times enters directly into agreement with input suppliers, service providers, donors and export outlets such as Saudi Arabia. It has so far 25 member farmer cooperatives that are engaged in the production of different vegetable and fruit crops in addition to banana (Annex Table 9.1.1.2.). Such collective action of farmers in the Gamo-Gofa zone has empowered and enabled them overcome various barriers, own their own storage and transportation facilities, build up their production skills, get access to extension and information services, and at large become part of the market economy compared to those in Bench-Maji and Sheka zones.

Farm-gate collectors

These are sometimes referred to as farm gate level “assemblers” or “forwarders”. They are often village based licensed middlemen or intermediaries who purchase the newly harvested banana at farm gate from the direct producers and forward it to wholesalers that are found in the major regional and central markets. Farmers get the harvested banana bunches to nearby farm gate collection centers where they often pile them under natural tree shades or in the open covered with banana leaves. The farm gate collectors then hire trucks and purchase and forward the bananas to the regional or central market wholesalers often on contractual agreement basis. In this case, the wholesalers send them the money through their bank accounts. At times, the wholesalers send their own hired trucks to the farm gate and purchase the bananas either directly from the producers or through the farm gate collectors. In both cases, the farmgate collectors operate as brokers in between the producers and wholesalers and gain their profit margins for their facilitation services from the wholesalers. Bananas are transported on piled lose bunches either by open ISUZU (5 to 5.5 tons load capacity) or FSR (8 to 9 tons load capacity) trucks. Such officially licensed middlemen are found only in the banana producing villages of the Gamo-Gofa zone and there were 104 of them at the time of the survey work; of which 76 were in Arba-Mich Zuria district and 28 in Mirab-Abaya district (Arba-Munch Zuria Distric Agricultural Product Marketing Office, 2014); Mirab-Abaya District Agricultural Product Marketing Office, 2014).

Wholesalers

These are banana traders that operate mostly at major regional and central market outlets. They buy the bananas in bulk either directly from producers or through the licensed farm gate collectors and ripen and sell them to individual and institutional retailing business operators (green grocers, supermarkets, street and open market vendor, etc.). After the bananas are unloaded upon arrival, they are sorted, weighed and treated for ripening initiation for 2 to 4 days, depending on the locality or prevailing temperature. The ripening process is done through the traditional kerosene smoking system inside airtight and non-ventilated chambers commonly called “chella” or “muket” houses (Annex Figures 9.2.10 and 9.2.11.). Ripening is most commonly done on piled bunches of 5 to 10 layers (only ETFRUIT and a few whole sellers perform the ripening process in hands, Annex Figure 9.2.11.). After ripening, bunches are dehanded and sold to various retailers in their respective localities either in green-ripen or yellow-ripen forms. Some wholesalers located close to the export outlets (Dire-Dawa, Harar and Jigjiga; sometimes ETFRUIT as well) are engaged in green banana exports to neighboring Djibouti and Somaliland (Annex Figures 9.2.6. and 9.2.7.).

Retailers

These are traders that purchase either green-ripe or yellow-ripe bananas after dehanding from wholesalers/ripeners and sell them to consumers. When they buy the green-ripe bananas, they often cover them with newspapers for another 2-4 days (depending on the prevailing temperature) and keep them until they develop the ultimate yellow color before they sell them to the ultimate consumers (Annex Figures 9.2.13 and 9.2.14).

Consumers

Consumers are categorized into individuals, households, and public and private institutional types. Households form the bulk of the consumers in the market. Institutional consumers include, juice houses, cafeterias, hotels, restaurants, hospitals, universities, etc. (Table 11.).

Export buyers

These are foreign traders often in the neighboring countries of Djibouti and Somaliland, and at times Saudi Arabia, who purchase fresh bananas from Ethiopia and do the subsequent business within the market channels in their respective countries (Table 11.).

Table 10. Overview of major banana market places and marketing information in Ethiopia

Outlet	Distance from A/Minch (km)	Cost of transport (Birr)		No. of ripeners	No. of “chella” houses	No. of wholes alers	Av. No. hours for ripening in “chella” houses	Av. No. hours for yellowing wooden boxes	Av. price/kg of green-unripe banana	Av. wholesaler selling price of Green-ripe banana to retailers/kg (Birr)	Av. wholesaler selling price of yellow-ripe banana to retailers/kg (Birr)	Av. retailer selling price of yellow-ripe banana to consumers/kg (Birr)	Av. Street vendors selling price of yellow-ripe banana to consumers/kg (Birr)
		ISUZU	FSR										
Arba-Minch	-	-	-	0	0	1	-	-	4	-	6	7	8
Hawassa	280	3000	5000	6	9	6	16-20	24-36	5.5	6.5	7.5	8.5	10
Adama	455	5000	9000	9	16	9	18-24	24-36	4.75	6.75	7.75	9.5	11
Addis Ababa	505	6000	10000	38	92	92***	36-48	30-36	5.50	8.5	9.00	12	12
Assela	555	6500	9500	1	1	1	36-48	30-36	5.0	7.0	9.0	12	12
Harar	955	12000	21000	4	7	6	24-36	24-36	5.25	7.5	8.75	12	12
D/Dawa	955	12000	21000	0	0	6***	-	24-36	-	10.0	11	15	15
Jigjiga	1055	13000	23000	5	9	7	24-36	24-36	5.5	9.0	11	12	12
Tog-Wajaale	1145	13500	-	1	1	1	-	-	5.5	9.0	11	13	13
Dessie	905	11500	18500	6	11	12	36-48	30-36	5.5	8.5	11	12	12
Woldiya	1025	12300	18000	6	8	6	24-36	24-36	5.5	8.5	11	12	12
Mekelle	1288	13500	22000	22	33	22	36-48	30-36	5.5	8.5	11	12	12
D/Markos	835	8000	12000	2	2	2	24-36	24-36	5.25	8.5	11	12	12
B/Dar	1055	10000	14000	1	1	6	18-24	24-36	5.25	9.0	11	13	13
Gondar	1215	12000	21000	4	7	4	36-48	30-36	5.5	9.5	11	13.5	13
Metema	1395	14000	-	0	0	3	-	18-24	-	9.5	11	20	20
Jimma	860	11000	-	3	5	7	18-30	24-36	5	8.5	11	12	12
Mizan	-	-	-	-	-	-	-	-	5	-	-	8	10
Tepi	-	-	-	-	-	-	-	-	5	-	-	9	10
Gelabat	1397	-	-	-	-	-	-	-	-	-	-	22	-
Hargeisa	1092	-	-	-	-	-	-	-	-	-	-	1.75 (USD)*	-
Djibouti	1064	-	-	-	-	-	-	-	-	-	-	1.55 (USD)**	-

Source: Own survey result, 2014/15
*, **=information collected from Jigjiga and Dire-Dawa Customs and Revenue Offices respectively; ***Includes ETFRUIT
“Chella” or “Muket” houses= banana ripening houses using kerosene smoking; Birr= Ethiopian currency (equivalent to 0.05 USD at the time of the survey)

3.6.4. Banana marketing channels

Banana is an important fruit crop in Ethiopia and goes through the hands of several supply chain actors. Based on the direction of flow, 13 different banana market channels were identified in this study (Figure 2 and Table 11). The channels start either from small-scale or large-scale producers and end up either domestically with the final consumers or the export terminal markets of Djibouti, Hargessa and rarely Jeddah.

The volume of banana transacted in the channels is quite different with the first five being currently the most dominant. For example, Table 9 shows the amount of banana distributed from January 1, 2013 to Dec. 30, 2013, to the major regional and central markets in Ethiopia through the five major market channels, just from the two major banana growing districts of the Gamo-Gofa Zone (Arba-Minch Zuria and Mirab-Abaya Districts). Ethiopia was also able to export about 80 tons of bananas to more distant export markets such as Suadi Arabia using reefer containers (EHDA, 2012). The trend was planned to continue with an export of 1000 tons per month (EHDA, 2012) but that could not be materialized due to problems like high level of inland transport costs through the standard temperature controlled reefer containers. The actors involved in the supply chain invariably face some kind of marketing charges and postharvest loss challenges as the produce moves from one chain to the other. The marketing charges being related to transportation, loading, unloading, handling, and ripening, the postharvest challenges are related to the inherent bulkiness and perishability of the produce, and rudimentary transportation (vehicles and roads), handling (loading and unloading), packaging, storage, and ripening facilities and systems.

3.6.5. Marketing margin analysis

The term marketing margin commonly refers to the difference between producer and consumer prices of an equivalent quantity and quality of a commodity (Tomek *et al*., 1990). As such, marketing margins for the major domestic marketing channels, where most of the banana transactions are taken place, are calculated by means of the following formula (Table 11).

$$GMM = \frac{\text{Selling price} - \text{purchase price}}{\text{Consumer Price}} \times 100$$

Of the total 10 villages included in the study, only four of those in Gamo-Gofa zone (Sele-Kanchama, Ocholo-Lante, Omo-Lante and Ankober) have farmer cooperatives through which the majority of farmers sell their banana. Selling of newly harvested bananas at farm gate through farm gate collectors is the most common marketing practice in most of the study areas.

Table 11. Distribution of Gross Market Margins of actors across the major banana marketing channels, *2014/15*

Market channel	Domestic Markets**													Importers in Export Markets**		
	Small-scale Growers*		Large-scale Growers*		Farm-gate collector		Farmer Cooperatives /Union		Wholesalers		Retailers		Consumers	Djibouti	Hargeisa	Jeddah
	Birr/kg	%	Birr/kg	%	Birr/kg	%	Birr/kg	%	Birr/kg	%	Birr /kg	%	Birr/kg	Birr/kg	Birr/kg	Birr/kg
Channel 1	4.0	33.3	-	-	1.5	12.5	-	-	3.00	25	3.50	29.17	12.0	-	-	-
Channel 2	4.0	33.3	-	-	-	-	-	-	4.50	37.5	3.50	29.17	12.0	-	-	-
Channel 3	3.5	29.2	-	-	-	-	2.00	16.7	3.00	25	3.50	29.17	12.0	-	-	-
Channel 4	-	-	4.0	33.3	1.5	12.5	-	-	3.00	25	3.50	29.17	12.0	-	-	-
Channel 5	-	-	4.0	45.8	-	-	-	-	3.00	25	3.50	29.17	12.0	-	-	-
Channel 6	4.0	50.0	-	-		-	-	-			4.0	50	8.0	-	-	-
Channel 7	4.0	12.9 (11.4)	-	-	1.5 (1.5)	4.8 (4.3)	-	-	25.5 (29.5)	82.3 (84.3)	-	-	-	31.0	(35.0)	-
Channel 8	4.0	12.9 (11.4)	-	-	-	-	-	-	27.0 (31.0)	87.1 (88.6)	-	-	-	31.0	(35.0)	-
Channel 9	3.5	43.8	-	-	-	-	3.5	43.8	-	-	1.0	12.5	8.0	-	-	-
Channel 10	3.5	11.2 (10.0)	-	-	-	-	2.0 (2.0)	6.5 (5.7)	25.5 (29.5)	82.3 (84.3)	-	-	-	31.0	(35.0)	-
Channel 11	3.5	-	-	-	-	-	1.0	-	-	-	-	-	-	-	-	NA
Channel 12	-	-	4.0	17.7 (15.7)	-	-	-	-	25.5 (29.5)	82.3 (84.3)	-	-	-	31.0	(35.0)	-
Channel 13	-	-	4.0	100.0 (100.0)	-	-	-	-	-	-	-	-	-	31.0	(35.0)	-

Source: *Calculated from own survey result, 2014/15;*

*Small-scale and large-scale growers, and licensed farm-gate collectors in Gamo-Gofa zone; **Channel actors in Addis Ababa and current export markets;

( )= Gross market margins in brackets are calculated based on import prices in Hargeisa;

NA= data not available; **Birr=** Ethiopian currency (equivalent to 0.05 USD at the time of the survey);

Av. Large-scale growers' selling price to wholesalers in Addis (Birr/kg) =5.50; **Av.** Farm-gate collectors selling price to wholesalers in Addis (transports costs borne by farm-gate collectors),Birr/kg=5.50

Farmer cooperatives/unions selling price to wholesalers in Addis Ababa (transports costs borne by cooperatives/unions, (Birr/kg) =5.50

Av. wholesalers selling price of green-ripe banana to retailers in Addis Birr/kg = (8.50).; **Av.** farmer cooperatives/union selling price to retailers in A/Minch town (Birr/kg)=7.00 ;

Av. farmer selling price to local retailers at farm gate in A/Minch Zuria & Mirab-Abaya Districts (Birr/kg)=4.00;

Av. Selling price of retailers to consumers in A/Minch Zuria and Mirab-Abaya Districts (Birr/kg)=8.00;

Av. Farm gate selling price of farmer coops/union in A/Minch Zuria District to direct exporters to Jeddah Birr/kg)=4.50; Average purchase price of importers in Hargeisa (USD=1.75USD/kg, i.e.=35 Birr/kg)

Average purchase price of importers in Djibouti (USD=1.55USD/kg, i.e.=31 Birr/kg); Average purchase price of importers in Jeddah=NA

3.6.6. Descriptive and econometric results of banana yield performance and its determinants

Different literatures, including (Lusty *et al*., 2003 and Bathan *et al*., 2010), have documented various household, farm and other socioeconomic characteristics as important factors to influence the yield of banana. Similarly, different household and farm characteristics were observed to affect the yield of banana in the study areas. Table 12 presents comparative descriptive results of yield and its determinants across the different study sites.

Table 12. Comparison of household and farm specific characteristics of banana producers by location (mean values)*

Variables	Whole sample	Gamo-Gofa	Bench-Maji	Sheka	F-value
Average Yield (ton/ha/year)	19.5	26.25	15	15	1190.70***
	(5.69)	(2.18)	(0.000)	(0.000)	(0.000)
Average Age (years)	48.15	48.35	48.6	46.87	0.392
	(8.99)	(9.27)	(8.74)	(9.12)	(0.676)
HH size within the productive age group (15<age<65 years)	4.77	4.77	4.8	4.73	0.008
	(2.33)	(2.38)	(2.33)	(2.30)	(0.992)
HH experience in banana prodn. (Years)	15	15.58	14.33	15.17	0.951
	(5.02)	(5.97)	(4.36)	(4.04)	(0.389)
Average no. of suckers allowed per hill	8.49	6.15	10.05	10.03	1016.84***
	(1.98)	(0.63)	(0.43)	(0.41)	(0.000)
Area allocated for banana (ha)	0.52	0.90	0.28	0.25	38.38***
	(0.53)	(0.67)	(0.08)	(0.000)	(0.000)
Gender of HHH (male %)	66.7	61.7	70	70	1.125
Type of planting sucker (%)					150***
-Mixed (sword, water and maiden)	60	-	100	100	(0.000)
-Sword only	40	100	-	-	
Method of banana production (%)					150***
- rain-fed	60	-	100	100	(0.000)
-irrigated	40	100	-	-	
Use of spacing technology (yes %)	84.7	100	76.7	70	18.79***
Cooperative membership (yes %)	40	100	0	0	150***
Extension service on banana (yes %)	53.3	100	25	16.7	95.87***

*** denotes significance at 0.01 level (P<0.01); items in bracket are standard deviations; *Numbers in brackets denote standard deviations (SD)

Source: Own survey result (2014/15)

The result in Table 12 indicates that the yield of banana by producers in Gamo-Gofa area is substantially higher than those of Bench Maji and Sheka zone. Also area allocated for banana production is significantly higher in Gamo-Gofa zone than in Bench-Maji and Sheka zones.

Table 13. Brief descriptionof small-scale banana production areas covered through the survey

Region	Zone	Wereda (District)	Kebelle (Village)	No. of HHs interviewed	Area of banana (ha)	Major cultivars grown*	Minor cultivars grown		Av.yield/ha (ton)
SNNPR	Gamo-Gofa	Arba-Minch Zuria	Sele Kanchama	15	1450	Poyo ("Mekakelegna Ambo), G/C ("Tiliku-Ambo")	D/C ("Dinke"), Williams I, G/Naine		30.1**
			Ocholo-Lante	15	813.1	Poyo, G/C, D/C	Williams I, G/Naine, Ducasse, locals		26.5**
		Mirab-Abaya	Ankober	15	257.0	Poyo, G/C, D/C	"		23.2**
			Omo-Lante	15	785	Poyo, G/C, D/C	"		25.8**
	Bench-Maji	North-Bench	Fakatin	15	NA	D/C, G/C	Ducasse Hybrid, locals		14.22
			Gorit-ena-Mag	15	NA	D/C, G/C	"		15.31
		South-Bench	Kitte	15	NA	D/C, G/C	"		15.65
			Fanika	15	NA	D/C, G/C	"		14.92
	Sheka	Yeki	Addis Birhan	15	NA	D/C, G/C	"		14.71
			Fide	15	NA	D/C, G/C	"		16.12
Total	3	5	10	150	-	-	-		-

Source: Own survey result, 2014/2015

Where: HHs= Households; ha= hectare; G/Naine=Grand Naine; D/C=Dwarf Cavendish; G/C=Giant Cavendish; NA= data not available

*All farmers use suckers as planting materials; ** Farmers grow banana under irrigated condition

Table 14. Brief description of large-scale commercial banana farms covered through the survey

	Region	Zone	Wereda (District)	Name of Farm	Area of banana (ha)	Cultivars grown	Panting. Material	Av. Yield/ha (ton)
1	SNNPR	Gamo-Gofa	Mirab-Abaya	South Industrial PLC	15	Poyo, D/C, William I, G/Naine	Suckers & plantlets	30.21
			"	Gedika banana farm PLC	40	"	"	18.15
			A/M/Zuria	Omotic General Trading PLC	38	Poyo, G/C, D/C, William I, G/N, Vallery	"	31.72
				Kayiro Zamba Banana Farm	12	Poyo, G/C, D/C, William I, G/Naine	Suckers	27.71
				Mirabu-Girma Banana Farm	15	"	Suckers	26.63
				Amibara Agric.Dev't PLC	100	Poyo, G & D Cavendish	Suckers	18.05
				A/Minch Sericulture/Banana Farm	8	Poyo, G/C,D/C, William I, Grand Naine	Suckers	25.85
				Mulat Hailu Banana Farm PLC	7	"	Suckers	27.50
				Lucy Agri. Dev't PLC	120	Poyo, G/C, William I, G/Naine	Suckers	24.50
		Bench-Maji	S/Bench	Bebeka Coffee Estate Share Co.	45	D/C	Suckers	12.85*
		Sheka	Yeki	Tepi Green Coffee Estate Sh.C.	30	D/C	Suckers	13.50*
		Keffa	Gimbo	Gojeb Agri. Dev't Ent.	150	Poyo, G/C, D/C, William I, G/Naine, Robusta, Butuzua	Suckers	16.50*
2	Tigray	N.W Tigray	T/Adiabo	Tekeze Fruit Growers Ass.	80	Poyo, G/C, D/C, William I, G/Naine	Suckers & plantlets	26.50
3	Amhara	N/Wollo	Raya-Kobo	Kobo-Girana Banana Farm PLC	50	G/Naine	Plantlets	29.60
Total	3	6	7	14	672	-	-	-

Source: Own survey result, 2014/2015 *Grow banana under rain- fed condition

Where: ha= hectare; G/Naine (G/N)=Grand Naine; D/C=Dwarf Cavendish; G/C=Giant Cavendish; S/Bench=South-Bench; A/M/Zuria=Araba-Minch Zuria

As far as the method of production is concerned, all producers in Gamo-Gofa zone use irrigated production system while all farmers in Bench-Maji and Sheka zones follow the rain fed system (Tables 12, 13 and 14; Annex Table 9.1.1.1.1 and Annex Figure 9.2.4). There is also a significant difference on the type and number of suckers allowed per hill (clump) by producers across the three zones. Producers in Gamo-Gofa zone maintain lower and more appropriate number of suckers than those in Bench Maji and Sheka zones. In addition, banana producers in Gamo-Gofa zone use only sword suckers as planting materials while those in Bench-Maji and Sheka zones use mixed suckers (sword, water and maiden suckers). While almost 100% of farmers in Gamo-Gofa zone also use regular spacing technologies of 3m to 4m, only 76.7% of the farmers in Bench-Maji and 70% in Sheka zone consider spacing as an important production factor for banana. This can be related to differences in extension services as only producers in Gamo-Gofa zone reported to get some level of extension services on banana. Besides, the majority of banana growers in Gamo-Gofa zone are members of their respective village level farmer cooperatives through which knowledge and experience can be shared among members. Therefore, the substantial yield difference between producers in Gamo-Gofa zone and those in Bench and Sheka zones can be attributed to the aforementioned differences in production techniques as well as access to extension, experience-sharing and information services (Table 12).

Besides, in order to determine and quantify the impact of the explanatory variables or factors affecting the yield performance of banana (production inputs, household and farm characteristics, etc.) in the study areas, multiple linear regression analysis was employed on the pooled data from the above table. Table 15 depicts the regression results of the effects of these explanatory variables on yield of banana.

Table 15. Regression results of the effects of selected explanatory or yield influencing variables

Variables	Regression Coefficients	T-value
	(standard errors)	(P-value)
Topography 1 (1.Sloppy)	-0.00004	-0.004
	(0.012)	(0.997)
Topography 2 (1. Flat land)	0.002	0.125
	(0.016)	(0.900)
Age of HHH	-0.065	-1.607
	(0.04)	(0.110)
HH size within the productive age group (15<age<65)	0.002	0.122
	(0.017)	(0.903)
Experience in banana production	0.006	0.463
	(0.013)	(0.644)
No.of suckers allowed per hill	0.0002	0.004
	(0.054)	(0.996)
Type of sucker planting material (1. Sword suckers)	0.512	17.15***
	(0.030)	(0.000)
Use of spacing (1.yes)	0.001	0.050
	(0.021)	(0.960)
Area of land for banana	0.048	6.32***
	(0.008)	(0.000)
Constant	3.002	16.61
	(0.181)	(0.000)
No. of observation	150	
Adjusted R^2	0.974	
F-value	628.71***	

Source: Calculated from own survey result (2014/15)

*** denotes significance at 0.01 level (***,**, and *significant at 1, 5 and 10 percent probability level)

Based on various literatures and the available data, topography, soil type, age, household size within the productive age, number of suckers allowed per hill, type of sucker used as planting material, use of spacing technology, area of banana land holding and method of production (rain fed or irrigated) were identified or selected to be used in the regression model as determinants of banana yield performance (Table 15). Out of the selected variables, soil type and method of production were excluded from the analysis due to multi-collinearity problem.

According to the results of the multiple regression analysis, the two variables of type of banana planting materials (suckers) used as planting materials and area of banana land holding for production, were found to have a significant effect on yield (Table 15). As the probability of using sword suckers for planting material increases by 1 unit, yield of banana will also increase by 0.512 percent. In addition, as the area of land allocated for banana increases by 1 unit, yield can increase by 0.048 percent. Since the summation of the significant coefficients (0.512 + 0.048= 0.560) is less than 1, it can be said that banana production in the surveyed areas is characterized by decreasing returns to scale (output is proportionately less as related to the proportion of input used).

CHAPTER 4: ASSESSMENT OF BANANA POSTHARVEST HANDLING PRACTICES AND LOSSES IN ETHIOPIA

Abstract

The study was conducted to assess the status of postharvest handling practices and associated loss of banana in Ethiopia. The farm level postharvest handling and loss data were collected from 3 major banana producing zones, 5 districts, 10 farmer villages and 14 large-scale commercial farms. The market level postharvest handling and loss data also encompassed 19 major towns scattered throughout Ethiopia. As such a total of 150 small-scale and 14 large-scale growers, 59 wholesalers/ripeners, 53 retailers and 53 consumers were interviewed using structured and semi-structured questionnaires. Secondary data was also collected from written documents and focus group discussions (stakeholders) across the survey areas. Results of the study indicated that the aggregate postharvest loss of banana was estimated to be 45.78%, of which about 15.68% was incurred at farm, 22.05% at wholesale (including transport from farm gate and ripening), and 8.05% at retailer or purchase to end-user sale levels. Of the causes of postharvest loss accounted during banana transport from the farm gate, impact and finger breakage damages purely accounted to 20% while the remaining 80% also included physiological and other mechanical damages like compression, abrasion, bruising and puncturing. Being a delicate and highly perishable crop, results of the multiple regression analysis indicate that market distance, duration of transport, storage condition, storage duration, duration of ripening, type of ripening rooms, means of bunch transport, experience in banana marketing, etc. were found to be important determinants of the postharvest loss of banana in Ethiopia. The study generally indicate that even though the country has vast potential for banana production, the supply chain is facing several limitations and constraints that include high yield variability, crop management practices, and high produce perish ability and postharvest losses throughout the handling stages. These points out the need for increased research and extension services as well as improvement in postharvest handling (transportation, storage, packaging and ripening) and marketing infrastructure and facilities.

Keywords: Banana, supply-chain, postharvest handling, postharvest loss, determinants

4.1. Introduction

Dessert banana and plantain *(Musa spp.)* are the fourth most important staple food crops in the world after rice, wheat and maize (Salvador *et al*., 2007). They are also important sources of income for many smallholder Sub-Saharan Africa farmers (FAOSTAT, 2012). In Ethiopia, dessert banana is the major fruit crop that is most widely grown and consumed. It grows in several parts where the growing conditions are conducive. It contributes around 47.83% for producers' own consumption, 49.19% for income generation, 0.47 for animal feed and 2.52% for other purposes (CSA, 2014). Banana covers about 59.64% (53,956.16 hectares) of the total fruit area, about 68.00% (478,251.04 tones) of the total fruits produced, and about 38.30% (2,574,035) of the total fruit producing farmers in Ethiopia (CSA, 2014). On the other hand, about 68.72% (37,076.85 hectares) hectares of land covered by banana, about 77.53% (370,784.17 tones) of the banana produced and 22.38% (1,504,207 tones) of the banana producers in Ethiopia are found in the Southern Nations Nationalities and Peoples' National Regional State- SNNPRS (CSA, 2014). Gamo-Gofa, Bench-Maji and Sheka zones are among the major banana producing zones of the SNNPRS, of which Gamo-Gofa zone alone covers over 70% of the total banana marketed across the major market outlets in Ethiopia (CFC, 2004).

Despite the above stated facts and the concerted effort being made by the government of Ethiopia to promote and diversify its agricultural outputs as well as exports at large, the attention given to banana especially in terms of research, extension services, investment endeavors and overall value-chain management has been very limited. As documented by CSA (2009), banana in Ethiopia is so far grown on less than 1% of the Ethiopia's gross cropped area contributing less than 0.8% of the gross value of agricultural outputs and quite negligible in export earnings. In most parts of the country, its production has yet been limited to backyard and small-scale productions with the produce largely supplied to local markets. Although there have been some recent renewed interests for large scale banana production, their impact is so far insignificant and operationally not much beyond the role played by small-scale farmers. Large scale banana production in Ethiopia covers only 0.19 % (1,910.97 hectares) of the total area covered by banana and 0.22% (17, 924.59 tones) of the total banana produced in Ethiopia (CSA, 2014). All the same, about 93.38 % (1,784.39 hectares) of the total area covered and about 92.73% (16, 620.76 tones) of the total banana produced by large-scale production in Ethiopia is found in the Southern Nations Nationalities and Peoples' National Regional State- SNNPRS (CSA, 2014).

The role of small-scale farmers is by and large limited to production and farm gate selling (Annex Figure 9.2.6.). After harvest, they sell their banana to either local licensed farm-gate collectors, farmer cooperatives/unions when any, directly to distant market traders who purchase the banana at farm-gates, or to a limited extent to local market retailers and roadside vendors. When bananas are sold to local licensed farm-gate collectors and farmer cooperatives/unions, they are forwarded or transported piled in lose bunches without any package to major urban centers by open or non-refrigerated ISUZU or FSR trucks (Annex Figures 9.2.6., 9.2.7. and 9.2.9.). They are then sold directly or on contractual agreement basis to wholesalers across the major regional and central towns of the country who at the same time do the ripening operation through the traditional kerosene smoking system. The wholesalers then distribute it to close or distant retailers (supermarkets, green grocers, street or roadside vendors, traditional open market retailers, etc.) in their respective localities. Retailers often purchase green ripe bananas from wholesalers and keep them till they develop the ultimate yellow color before they sell them to the final consumers (Annex Figures 9.2.13. and 9.2.14.).

The actors involved in the banana supply chain in Ethiopia invariably face some kind of postharvest loss challenges as the produce moves from one chain to the other. The postharvest losses are related to a combination of factors including the inherent bulkiness and perishability of the produce, and rudimentary mode of transportation (vehicles and roads), handling (loading, unloading, packaging, storage, etc.), and ripening facilities and systems. Similarly, CFC (2004) and EHDA (2012) reported that the problem of banana export in Ethiopia is not merely due to low production and lack of markets, as it is located next door at least to the major consumer countries of the Middle-East, but due to a combination of factors that include improper mode of transportation (lack of logistics management for cool-chain management such as refrigerated trucks and reefer containers, inadequate road infrastructure and rough produce handling, lack of postharvest treatments, etc.), absence of packinghouses close to major production areas, and improper harvest maturity determination and harvesting techniques

Similar studies on postharvest loss of banana in Ethiopia were carried out earlier on certain localities and losses ranging from 26.5% (Mulualem *et al*., 2015) to 30-40% (Dawit Alemu *et al*., 2008) were reported at various levels of handling. Correspondingly, the present study was initiated with a major thesis to investigate the existing banana postharvest handling practices and associated losses in a wider scale at country level whereby gaps could be identified for concomitant holistic interventions into the future.

4.2. Research Methodology

4.2.1. Description of the survey areas

The banana production sites and market places covered by the survey are shown in Figure 3.1.

4.2.2. Description of the banana production areas covered by the survey

The survey on postharvest handling and loss at smallholder banana producers level was solely conducted in the Southern Nations Nationalities and Peoples' Regional State (SNNPR) of Ethiopia covering 3 zones (Gamo-Gofa, Bench-Maji and Sheka), 5 woredas (districts) and 10 kebeles (farmer villages). It is an important region where the bulk (77.53%) of the banana produced in Ethiopia is found (CSA, 2014). Almost all the banana commercially sold in all the major towns of Ethiopia, including Addis Ababa, is produced in this region, with Gamo-Gofa comprising over 65% of the market share, Bench-Maji 10% and Sheka 5% (CFC, 2004). Only the balance comes from other pocket areas of the country that are less known for banana production (CFC, 2004). Banana in those areas is a major component of livelihood strategies, which constitutes an important food security and household source of income for many farmers (CFC, 2004). Thus, in those zones, a total of five districts, 10 major banana producer villages, and 150 farm households were considered for the survey work at producers' level (Table 7 and Figure 1.). All the same, as shown in Table 7, the study on the large-scale commercial production of banana was also carried out on a wider part of the country covering 14 farms from 3 national regional states (SNNPR, Tigray and Amhara).

4.2.3. Description of the banana market places covered and supply chain actors consulted across the survey areas

As shown in Table 8 and Figure 1, the market level study on banana postharvest handling and loss was carried out across 19 major regional and central towns in Ethiopia. They are normally the centers where the traders (wholesalers, retailers and exporters), market regulatory institutions as well as the bulk of the ultimate consumers are found. In this respect, the study was started at farm gate level and proceeds all the way to the end of the banana supply chain in Ethiopia. The study adopted a number of alternative approaches for generating both quantitative and qualitative data. It included extensive interviews and discussions with the direct marketing actors as well as private and public enterprises such as research, extension, marketing and regulatory institutions. A systematic random sampling was employed and accordingly a total of 12 licensed farm gate collectors, 6 farmer cooperatives/union, 59 wholesalers/ripeners, 53 retailers, 53 final consumers and 4 market regulatory institutions (i.e. Customs & Revenue Branch Offices) were considered for the study (Table 8 and Table 10).

4.2.4. Method, source and type of data collected

The findings in this study took into account and describe the existing situation of banana postharvest management in Ethiopia. Both quantitative and qualitative data collection methods were employed using a cross sectional type of research approach in the primary and secondary information collection process. The primary data was collected through interviews by using structured and semi-structured questionnaires with key informants from the supply chain actors, all the way from the producers up until the final consumers. The structure of the questionnaire was designed as both open and close ended questions (**Annex Tables 9.1.4.).** The close ended questions were designed as list or select any appropriate/correct answer and they were coded. The open ended questions were designed in such a way to allowing the respondents to freely express their ideas. In addition to the questionnaires, focus group discussions were carried out with all banana supply chain actors (producers, traders, farmer cooperatives/unions, researchers, extension workers and regulatory bodies). The secondary data was acquired from published and unpublished reports of different levels of actors such as line national, zonal, district and village level agricultural extension, research, marketing, cooperative, customs and revenue, statistics, and NGO offices as well as internet (website) search based information (**General Annex Section 4: Survey Itinerary).**

4.2.5. Sampling technique

A multi-stage purposive and random sampling technique was employed to collect all the necessary primary data. Initially, five major banana producer districts were purposively selected jointly with the respective zonal agricultural offices on the basis of volume of banana production. Then, 10 major banana producer farmer villages (2 villages/districts) were similarly selected purposively jointly with the respective district agricultural offices. Finally15 households were randomly selected from each village from the total list of households provided by each of the village level agriculture offices.

Developments Agents (DAs) of the respective study villages were largely used as enumerators to work alongside the researcher. They were given about half a day briefing by the researcher on the contents of the structured questionnaire and way of handling of the interview. The other banana supply chain actors (farm-gate collectors, wholesalers, ripeners, retailers, consumers and other stakeholders) were interviewed using other separate structured questionnaires to generate primary data. As such a total of 150 small-scale farmer household, 14 large-scale (commercial) growers, 59 wholesalers/ripeners, 53 retailers and 53 consumers were randomly selected based on size proportional probability and interviewed in the primary data collection process using the respective structured questionnaires (Table 7 and Table 8).

4.2.6. Method of data analysis

The SPSS (Statistical Package for Social Sciences) software was used for data entry and analysis. A descriptive statistics was used that include parameters such as sum, mean, percentage, etc. In addition, mean comparison techniques such as ANOVA and independent sample–t test were employed to compare the differences in banana postharvest losses among the supply chain actors or handling practices. In order to identify the determinants of the banana postharvest losses at different handling stages, the following multiple linear regression models were used using the amount of postharvest losses through various factors as dependent variables and other explanatory variables such as the type of postharvest handling and marketing systems as independent variables.

$$Y1 = \beta 0 + \beta 1\ F1 + \beta 2\ F2 + \beta 3\ F3 + \beta 4\ F4 + \beta 5\ F5 + \beta 6\ F6 + \beta 7\ F7 + \beta 8\ F8 + \beta 9\ F9 + \beta 10\ F10 + \beta 11\ F11 + \beta 12\ F12 + \beta 13\ F13 + \varepsilon \quad \textbf{(1)}$$

Where:

Y1= A dependent variable indicating the amount of **farm-level postharvest loss per trip caused** by various factors (%)

F1=Age of the household head; F2=Household size; F3=Household experience in banana business (production or marketing); F4=Area of land allocated by the household for banana production; F5=Market distance from the farme-gate; F6=Duration (no. of days) of banana storage; F7=Banana transport to farm-gate collection centers by human labor; F8= Banana transport to farm-gate collection centers by pack animals; F9=Banana transport to farm-gate collection centers by donkey carts; F10= Banana storage under natural open shade; F11= Banana storage under ventilated shadehouse; F12=Banana storage under in the open sun covered with banana leaves; F13= Banana storage on the open sun without cover

$$Y1 = \beta 0 + \beta 1\ F1 + \beta 2\ F2 + \beta 3\ F3 + \beta 4\ F4 + \beta 5\ F5 + \beta 6\ F6 + + \varepsilon \quad \textbf{(2)}$$

Where:

Y1 = A dependent variable indicating the amount of **wholesale-level postharvest loss per trip** caused by various factors (%)

F1=Age of the household head; F2=Experinece in banana marketing; F3=Duration (no.of hours) required to transport banana from farmgate wholesale base town; F4=Duration (no. of hours) storage before ripening; F5= Structure of the ripening room (sealed masonary warehouse; F6= Structure of the ripening room (basement of masonary apartment)

$Y1 = \beta0 + \beta1\ F1 + \beta2\ F2 + \beta3\ F3 + \varepsilon$ **(3)**

Where:

Y1 = A dependent variable indicating the amount of **retail-level postharvest loss per trip** caused by various factors (%)

F1=Age of the household head; F2=Experinece in banana marketing; F3=Duration (no.of hours) required for consumer level ripening (yellow ripening)

4.3. Results and Discussion

4.3.1. Evaluation of the performance of the banana supply chain and postharvest loss analysis

The banana supply chain in Ethiopia comprises the following major segments.

Producers

These are both small-scale farmers and large-scale commercial growers involved in banana production. After harvest, small-scale farmers get the banana to the farm-gate and sell it either to local licensed farm-gate collectors, farmer cooperatives/unions when any, directly to distant market traders who purchase the banana at farm-gates, or to a limited extent to local market retailers and roadside vendors. Large-scale commercial growers mostly sell their banana directly to regional and central market-based wholesalers and seldom to farm gate collectors. Producers determine the harvest maturity stage of banana variously on the basis of finger angularity, fullness of fingers, color of fingers, or age of the male bud (flower). While the problem is mostly inclined towards harvesting immature fruits, there are also cases where bunches remained longer after maturity due to labor shortages and lower purchases by traders often due seasonal barriers to get trucks the farm gate collections centers. In both cases, such fruits will cause serious difficulties for even ripening and subsequently high level of postharvest losses be borne by wholesalers/ripeners. Producers invariably use bushman knives (locally called “gejera”) to harvest banana bunches and except for Dwarf Cavendish, they girdle first the pseudo-stems (Annex Figure 9.2.7a.) and then cut the bunches as they touch the ground. Subsequently, they carry them lose on the shoulders to intermediate collection points near the farm where they pile or put them side by side for a few hours to about one day long. Then, depending on the distance and available labor, they transport them to the central farm gate collection centers either similarly by human carriage or using donkey driven carts (Annex Figure 9.2.7b and Annex Figure 9.2.7c) where they pile them without cushioning under natural shade trees or in the open sun covered with banana leaves (Annex Firure 9.2.8.). Various physical and mechanical damages like impact, direct fruit breakage and spillage, bruising, abrasion, puncturing and compression damages are incurred in the process that cause huge postharvest losses at farm, farm gate as well as subsequent handling stages along the supply chain.

Farm-gate collectors

These are sometimes referred to as farm gate level "assemblers" or "forwarders". They are often village based licensed middlemen or intermediaries who purchase the newly harvested banana at farm gate from the direct producers and forward it to wholesalers that are found in the major regional and central markets. As stated above, farmers get the harvested banana bunches to nearby farm gate collection centers where they often pile them under natural tree shades or in the open covered with banana leaves. The farm gate collectors then hire trucks and purchase and forward the bananas to the regional or central market wholesalers often on contractual agreement basis. In this case, the wholesalers send them the money through their bank accounts. At times, the wholesalers send their own hired trucks to the farm gate and purchase the bananas either directly from the producers or through the brokers. In both cases, the farm gate collectors operate as brokers in between the producers and wholesalers and gain their profit margins for their facilitation services from the wholesalers. Bananas are transported on piled lose bunches either by open ISUZU (5 to 5.5 tons load capacity) or FSR (8 to 9 tons load capacity) trucks (Annex Figure 9.2.9.). In addition to the rough loading and unloading practices, such transportation system makes the banana bunches along the way heavily liable for impact, vibration, compression, abrasion, bruising and direct breakage damages. Such officially licensed middlemen are found only in the banana producing villages of the Gamo-Gofa zone and there were 104 of them at the time of the survey work; of which 76 were in Arba-Mich Zuria district and 28 in Mirab-Abaya district (Arba-Munch Zuria and Mirab-Abaya District Agricultural Product Marketing Offices, 2014).

Farmer cooperatives/unions

These are a group of village level farmers formally organized into farmer cooperatives or unions in order to market their banana and access or purchase inputs. The majority of farmers in the banana growing villages in Gamo-Gofa zone are organized into village level farmer cooperatives, with the cooperatives further organized as members of the Gamo-Gofa Farmers Vegetable and Fruit Marketing Cooperative Union PLC. This union is so far the only cooperatives' union engaged in banana business in Ethiopia. It is a strong union that, on behalf of its member cooperatives, at times enters directly into agreement with input suppliers, service providers, donors and export outlets such as Saudi Arabia. It has so far 25 member cooperatives that are engaged in the production of different vegetable and fruit crops in addition to banana (Annex Table 9.1.1.2.). Such collective action of farmers in the Gamo-Gofa zone has empowered and enabled them overcome various barriers, own their own storage and transportation facilities, build up their production skills, get access to extension and information services, and at large become part of the market economy compared to those in Bench-Maji and Sheka zones. The union collects the bananas from its member farmer cooperatives at central farm gate collection centers by weighing and registering the amount received from each farmer. In so doing, it sorts out the bunches for their maturity and various defects and removes the extra basal and apical portion of the bunch stem. It then loads them onto its own or hired trucks similarly on piled lose bunches cushioned only from the bottom end and sides with banana leaves (Annex Figure 9.2.9.). In this case too, although better attention is given to the handling of the banana fruits, some levels of postharvest losses related impact, bruising, abrasion, and compression damages owing to similar modes of loading, unloading, and transportation.

Wholesalers

These are banana traders that operate mostly at major regional and central market outlets. They buy the bananas in bulk either directly from producers or through the licensed farm gate collectors and ripen and sell them to individual and institutional retailing business operators (green grocers, supermarkets, street and open market vendor, etc.). After the bananas are unloaded upon arrival, they are sorted, weighed and treated for ripening initiation for 2 to 3 days, depending on the locality or prevailing temperature The ripening process is done through the traditional kerosene smoking system inside airtight and non-ventilated chambers commonly called “chela” or “muket” houses (Annex Figures 9.2.10, 9.2.11 and 9.2.12). Ripening is most commonly done on piled bunches of 5 to 10 layers (only ETFRUIT and a few whole sellers perform the ripening process in hands, Annex Figure 9.2.11.). After ripening, bunches are dehanded and sold to various retailers in their respective localities either in green-ripen or yellow-ripen forms. Here again, as a result of the rough unloading, weighing, ripening, and dehanding practices, bananas are heavily liable for impact, compression, bruising, abrasion, puncturing, direct breakage and over-heating damages. Nearly all wholesalers/ripeners also explained both immature and over matured fruits as regularly being part of the postharvest loss they incur. While the immature fruits either completely fail to ripe or ripe unevenly, the over mature ones often tend to be caked due to over ripening and cracked during the prescribed ripening treatment period. Some wholesalers located close to the export outlets (Dire-Dawa, Harar and Jigjiga; sometimes ETFRUIT as well) are engaged in green banana exports to neighboring Djibouti and Somaliland.

Retailers

These are traders that purchase either green-ripe or yellow-ripe bananas after dehanding from wholesalers/ripeners and sell them to consumers (Annex Figure 13). When they buy the green-ripe bananas, they often cover them with newspapers for another 2-4 days (depending on the prevailing temperature) and keep them until they develop the ultimate yellow color before they sell them to the ultimate consumers (Annex Figure 14). Here again, some losses due to physical, mechanical and physiological damages are variously incurred when they transport and handle them in open trucks, wooden boxes, and woven baskets as well as display them in the open sun and dusty places.

Consumers

Consumers are categorized into individuals, households, and public and private institutional types. Households form the bulk of the consumers in the market. Institutional consumers include, juice houses, cafeterias, hotels, restaurants, hospitals, universities, etc. (Table 11).

Export buyers

These are foreign traders often in the neighboring countries of Djibouti and Somaliland, and at times Saudi Arabia, which purchase fresh bananas from Ethiopia and do the subsequent business within the market channels in their respective countries (Table 11).

4.3.2. Descriptive and econometric results of factors of banana postharvest losses and its determinants

Postharvest losses of banana at the various chains before it reaches to the final consumers were assessed and results identified for the major determinants of postharvest losses are also presented in Table 16. Results were estimated as percentage of total production or amount handled at different stages of the supply chain.

Table 16. Estimated postharvest loss of banana at different stages of the supply chain

Levels /stages of product handling	Mean (%) (std.dev)
Farm level losses	
Harvesting	6.53 (1.32)
Transport and farm gate- storage	9.15 (1.22)
Total loss at the farm level	**15.68**
Ripeners (wholesale) level losses	
Farm-gate Loading and Transport	8.68 (2.32)
Unloading	3.73 (2.53)
Ripening	2.86 (1.37)
Selling to Retail Outlets	6.78 (2.42)
Total loss at the wholesale level	**22.05**
Retailers' level loss	
From purchase to sale (total)	8.05 (3.93)
Total loss at retail level	**8.05**
Grand total	**45.78**

Source: Calculated from own survey result, 2014/15

4.3.2.1. Farm level losses

The results in Table 16 revealed that the average total farm level loss of banana was 15.6 percent of the total production. From this total loss, the loss incurred due to improper transport and storage is much larger. Important postharvest factors that contributed to transport and storage losses at the farm level include impact, compression, breakage, and bruising damages. Farm level loss during harvesting was estimated to be 6.53 percent of the total production. Losses at harvest were mainly due to bunch and finger breakage, and impact and bruising damages.

4.3.2.2. Wholesale level losses

The average total postharvest losses at the wholesale level were estimated to be 22.05 percent of the total produce handled/purchased for sale. This amount is the largest of all postharvest losses at the different stages of handling and is mainly attributed to the losses incurred while transporting the produce all the way through from the place of farm gate purchase. The possible transportation problems that contribute for the loss include impact, compression, vibration, bruising, and breakage damages. Losses at the wholesale level also occur during unloading, ripening and selling, which also include various physical, mechanical and physiological damages. Of the causes of postharvest losses accounted during banana transport from the farm gate to regional and central markets, 20 percent of wholesalers purely reported impact and fruit breakage as cause of postharvest loss while the rest (80%) responded the cause to include physiological and other mechanical damages like compression, abrasion, bruising and puncturing as well (Figure 3.)

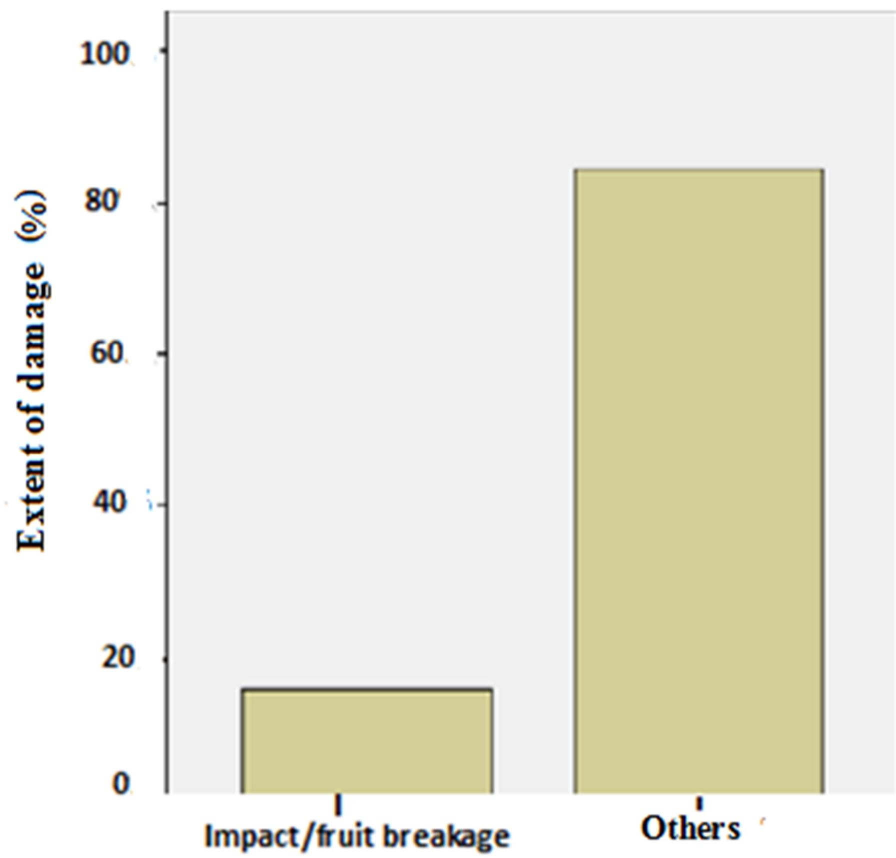

Figure 3. Major causes of postharvest loss during banana transport from farm-gate collection centers to regional and central wholesale markets

4.3.2.3. Retail level losses

The average total postharvest loss at retailing level (wholesale purchase to consumer sale) was estimated to be 8.05 percent. This amount is small as compared with the other handling stages stated above primarily due to the relatively rapid turnover of the produce in between the retailers and final consumers. The main causes of postharvest losses at the retail level include inappropriate display conditions (temperature, dust, etc.) and handling facilities (final ripening and handling boxes, shelves, etc.). In addition, losses at retailers' level are results of cumulative effects of poor postharvest handling from farm to the retail.

4.3.2.4. Determinants of postharvest loss of banana at the farm level

Based on literatures and available data, attempts were made to identify the determinants of postharvest loss of banana at the farm level using a multiple linear regression model. The results of the analysis are presented in Table 17.

Table 17. Multiple linear regression results on the effect of factors affecting farm-level postharvest loss of banana

Variables	Coefficients (Std. error)	t-values (P-values)
Age	0.011 (0.028)	0.404 (0.687)
HH size within productive age group (15<age<65)	-0.092 (0.101)	0.918 (0.360)
HH experience in banana production (years)	-0.064 (0.030)	-2.12** (0.036)
Area of banana land (ha)	-1.127 (0.313)	-3.60*** (0.000)
Market distance (Km)	0.683 (0.114)	6.01*** (0.000)
No. of days of storage	0.364 (0.174)	2.09** (0.038)
Means of bunch transport1 (1=human labor)	0.689 (0.609)	1.131 (0.260)
Means of bunch transport 2 (1= Pack animal)	0.463 (0.455)	1.02 (0.311)
Means of bunch transport 3 (1=carts)	0.544 (0.602)	0.903 (0.368)
Storage 1 (1= Under natural open shade)	-0.529 (0.462)	-1.15 (0.254)
Storage 2 (1= In open covered with banana leaves)	-0.19 (0.467)	-0.407 (0.684)
Storage 3 (1= under ventilated shade house)	-0.557 (0.534)	-1.042 (0.299)
Storage 4 (1= On the open sun without cover)	0.062 (0.728)	0.085 (0.933)
No. of observation	150	
R-square	0.585	
Adjusted R-square	0.546	
F-value	14.76***	

Source: Calculated from own survey result, 2014/15; ** and *** denote significance at 0.05 and 0.01 levels ; Where: HH=Household; No.=Number; ha= hectare; km=kilometer

The summary of the overall model suggests that the model is good enough to explain the relation between the dependent and the independent variables. The R-square values indicate that more than 50 percent of the variation in postharvest loss is explained by the selected independent variables. The significant F-value also reveals that the coefficients of the selected independent variables are significantly different from zero, indicating the goodness of fit of the model.

Thirteen independent variables (6 continuous and 7 dummies) were inserted in the model to assess their quantitative effect on proportion of postharvest loss of banana out of which four were found to have a statistically significant impact. As expected, household experience in banana production was found to have a negative and significant impact on proportion of postharvest losses. As experience increases by 1 year, the proportion of postharvest loss of banana was found to decrease by 0.064 percent. This can be related with the fact that as experience increases, producers get more awareness and knowledge on how to manage their operation so as to reduce postharvest losses and other operational costs. Area of land was introduced to measure the impact of scale of operation on postharvest losses. The result depicted that a one unit increment in banana land area could result in the reduction of postharvest loss by 1.13 percent. This result may contradict with the expectation that more can be lost when there is large production. On the other hand, it indicates how farms can be more efficient in reducing losses through improved techniques as their level of operation increases. Market distance and number of days of storage were found to have a significant and expected relation with the proportion of postharvest losses. As market distance increases by a unit, the proportion of postharvest losses was estimated to increase by 0.68 units. Increasing the number of storage days by a unit could also result in the increment of proportion of postharvest loss by 0.36 percent.

Despite its insignificant impact, the positive coefficients of all types of transport indicate that the existing means of transportation used by the producers in the area contribute for postharvest loss of banana. The positive sign of the coefficient on storage type on an open sun is also an indicator for using shade in storing banana to reduce its possible postharvest loss.

4.3.2.5. Determinants of postharvest losses at the wholesale and retail level

While assessing the determinants of postharvest losses at the wholesale and retail level, similar household and market characteristics have also been hypothesized. Out of the selected variables, ripening technique, transportation mechanism and type of banana cultivar purchased were excluded from the analysis as the responses were uniform throughout the sample. Table 18. shows the results of the regression analysis for determinants of postharvest loss at the wholesale and retail level.

Table 18. Multiple linear regression analysis results for determinants of postharvest loss at wholesale and retail levels

	Wholesale level		Retail level	
Variables	Coefficients (Std.error)	T-values (P-values)	Coefficients (Std.error)	t-values (P-values)
Age	-0.01	-0.105	-0.043	-0.463
	(0.098)	(0.917)	(0.093)	(0.646)
Experience in banana marketing	-0.333	2.879***	-0.149	-2.111**
	(0.116)	(0.006)	(0.071)	(0.040)
No. of hours required to transport banana from purchase site to base town	0.132	2.719***	-	-
	(0.049)	(0.009)	-	-
No. of hours of storage before ripening	0.181	1.068	-	-
	(0.169)	(0.290)	-	-
Duration of ripening (hours)	0.154	1.846*	3.947	3.822***
	(0.083)	(0.071)	(1.033)	(0.000)
Room type 1 for ripening (1=sealed masonry warehouse)	4.945	1.596	-	-
	(3.098)	(0.117)	-	-
Room type 2 for ripening (1=basement of masonry apartment)	6.47	2.022**	-	-
	(3.20)	(0.048)	-	-
Constant	16.25	2.998	-1.729	-0.324
	(5.42)	(0.004)	(5.341)	(0.748)
No. of observations	59		53	
R-square	0.305		0.245	
Adjusted R-square	0.210		0.199	
F-value	3.199***		5.30***	

Source: Calculated from own survey result, 2014/15, *, ** and *** denote significance at 0.1, 0.05 and 0.01 levels.
Where: No.=number; Std.=standard

The result in Table 18 indicates that experience in marketing have a significant impact in reducing postharvest losses at both the wholesale and retail level as increased experience helps to acquire more awareness and knowledge on the possible techniques of reducing losses. As the number of hours to transport banana from purchase site to a base town increases by 1 unit, the proportion of postharvest loss is estimated to increase by 0.13 percent at the wholesale level. Similarly, for a one hour increment in the duration of ripening, the proportion of postharvest loss is expected to increase by 0.154 and 3.94 percent at the wholesale and retail level respectively. Finally, ripening of banana at the basement of masonry house was found to increase postharvest loss by 6.47 percent at the wholesale level. This could be attributed to the possible buildup of temperature and carbon-dioxide under such conditions as a result of the absence of air circulation facilities under the traditional kerosene smoking ripening system invariably employed across the market outlets in Ethiopia.

CHAPTER 5: COMBINED EFFECTS OF 1-MCP AND EXPORT PACKAGING ON QUALITY AND SHELF-LIFE OF CAVENDISH BANANA *(Musa spp.)*

Abstract

The effect of four concentration levels of 1-methylcyclopropene-1-MCP (17.5µl/L), 10.5µl/L, 3.5 µl/L and 0 µl/L or untreated control) in combination with three levels of export standard banana packaging materials with modified atmosphere (MA) storage effect was investigated under ambient conditions (22±1 °C and 80 ± 5% RH) on shelf life and physicochemical quality attributes of Cavendish banana (Musa AAA Group, Cavendish Subgroup, cultivar 'Poyo', syn: 'Robusta'). Treatment with increased levels of concentration of 1-MCP and modified atmosphere packaging (MAP) generally extended shelf life and maintained better quality of fresh banana fruits when applied separately and in combination. The longest shelf life (36 days) with the lowest changes in physicochemical properties was obtained when fruits were kept in corrugated cardboard boxes with inner sealed or non-perforated polyethylene bags (PEP) after treatment with the highest concentration of 1-MCP 17.5µl/L. This could be credited to the higher inhibitory effect of 1-MCP on both the biosynthesis and action of ethylene when applied at the stated level of concentration and the stronger modified atmosphere (MA) condition created by the inner non-perforated PEP kept as lining within the corrugated cardboard boxes. Hence, this technique could be considered as a less sophisticated and less costly postharvest handling alternative (storage and transportation) under ambient conditions to the temperature controlled (14^{o}C) reefer container-based system currently employed in Ethiopia and elsewhere for fresh banana exports.

Key words: *Cavendish banana; 1-Methylcyclopropene (1-MCP), export standard packaging; shelf-life, physicochemical quality*

5.1. Introduction

Dessert banana and plantain *(Musa spp.)* are the fourth most important staple food crops in the world after rice, wheat and maize (Salvador *et al*., 2007). In Ethiopia, dessert banana, especially the Cavendish type, is the predominant fruit crop that is most widely grown and consumed. It contributes around 47.83% for producers' own consumption, 49.19% for income generation, 0.47 for animal feed and 2.52% for other purposes (CSA, 2014). Banana covers about 59.64% of the total fruit area, about 68.00% of the total fruits produced, and about 38.30% of the total fruit producing farmers in Ethiopia (CSA, 2014).

Banana is a highly perishable climacteric fruit that undergoes a very rapid metabolic process and senesces after harvest. Owing to such inherent characteristics, various handling and marketing technologies (storage, transportation, packaging, etc.) are commercially employed to extend its shelf life and maintain quality. However, in Ethiopia, the attention so far given to banana, in terms of research, extension services and overall supply-chain management has been very limited. As a result, the actors involved in the chain are invariably facing some kind of postharvest handling challenges as the produce moves from one point to the other. The challenges are related to the inherent bulky and perishable nature of the fruits, mode of transportation (vehicles and roads), handling (loading and unloading, packaging, and storage), ripening and marketing systems.

Explaining the challenges facing the export of banana from Ethiopia, EHDA (2012) and CFC (2004) similarly reported that they are not merely related to low production and lack of markets, as Ethiopia is located in relatively close proximity to the major consumer countries of the Middle-East. Instead, they explained that the challenges are related to lack of basic logistics for cool-chain management (refrigerated trucks, reefer containers, packaging materials, packinghouses, storage structures, postharvest treatment chemicals, etc.) as well as rudimentary harvest maturity determination and harvesting techniques. According to the same report, only small trial shipments of about 80 tons were exported to Saudi Arabia (Jeddah) in 2012 using temperature controlled (14^{o}C) reefer containers rented from maritime companies abroad. Although the trend was planned to continue with an export of 1000 tons per month, it could not be materialized due to the excessively high round trip rental cost of the reefer containers (7500-8000 USD) from the farm-gate in Ethiopia (Arba-Minch) to the destination market in Saudi Arabia (Jeddah). As reported by EHDA (2012), the length of time required to get the produce from the farm-gate (Arba-Minch) to the destination market in Jeddah was in the range of 4-5 days; including the 30-35 hours sea voyage from the port of Djibouti. This points out the need for an alternative less sophisticated and less costly postharvest handling technique that can extend the shelf-life of fresh banana fruits.

As an alternative, 1-methylcyclopropene (1-MCP) has been reported to have effective results in retarding ripening, prolonging shelf life and reducing postharvest loses in a broad variety of climacteric fruits including papaya, avocado, pear, plum, apple and sapodilla (Luo *et al*., 2009; Kashimura *et al*., 2010; Sauri-Duch *et al*., 2010). The impact of 1-MCP has also been reported to be more effective when applied in combination with modified atmosphere packaging-MAP (Watkins *et al*., 2000; Ketsa *et al*., 2013).

The evidence above signifies that the use of 1-MCP could similarly be a promising technology to extend the postharvest life of fresh banana fruits. Since the modest manufacturer price of 1-MCP (99.9% purity) as stated by Xianyang Xiqin Biotechnology Co., Lt., China: www.molbase.com/1-Methylcyclopropene) is 18.00 USD/g or 13,000.00 USD/ kg, it can as well serve as a low cost alternative to the current use of temperature controlled reefer container-based fresh banana exporting system from Ethiopia and elsewhere in the world.

Cognizant of this, the present experiment was initiated with the objective to investigate the effect of different concentrations of 1-MCP in combination with the currently employed export standard packaging materials on shelf life and physicochemical quality attributes of fresh banana fruits.

5.2. Materials and Methods

5.2.1. Description of the study area

The experiment was carried out at Jimma University College of Agriculture and Veterinary Medicine (JUCAVM), under the laboratory of the Department of Postharvest Management (PHM). JUCAVM is found in Jimma town, which is 355 km southwest of Addis Ababa, geogrpaghically located at about $7^0 4'$N latitude and $36^0 5'$E longitude with an altitude of 1780 meters above sea level. The mean maximum and minimum temperatures are 26.8^0C and 11.4^0C respectively, and the mean maximum and minimum relative humidity values are 91.40% and 39.92% respectively.

5.2.2. Experimental design and treatments

The experiment was laid out in a Randomized Complete Block Design (RCBD) with a 4*3 factorial arrangement in three replications. Blocking was found necessary since one side of the experiment room was was covered with glass windows, which could make the adjacent fruits more liable for exposure to the afternoon sun as well as to fluctuations in the external temperature. The factors were consisted of:

Factor A: 1-MCP concentrations in 4 levels:

Level 1: 17.5µl/L; **Level 2:**10.5µl/L; **Level 3:**3.5 µl/L; and **Level 4:** 0 µl/L, untreated control.

Factor B: Export standard banana packaging materials in 3 levels:

Level 1: Solid or non-perforated 5.7% Low Density (Gauge) Polyethylene (LDPE) bag with 0.91 g/cm^3 density and 0.038 mm thickness placed in telescopic corrugated cardboard boxes (local standard for banana export from Ethiopia)-(**P1)**;

Level 2:0.25% perforated 5.7% Low Density (Gauge) Polyethylene (LDPE) bag with 0.91 g/cm^3 density and 0.038 mm thickness placed in telescopic corrugated cardboard boxes **(P2)**; and

Level 3: Standalone telescopic corrugated cardboard boxes without inner polyethylene bags (PEP) **(P3)**.

The corrugated cardboard boxes were telescopic type with ventilation holes, having two pieces, i.e. the bottom being the weight bearing part made of 5 pliers (layers) and the top was a cover made of up 3 pliers. The dimensions of the cardboard boxes were 51cm*31cm*21cm with a capacity of 13.5 to 18 kg of banana fruits depending on market preference. The inner plastic bags (PEP) were of 80cm * 80cm sized low gauge or low density polyethylene bags (LDPE). Therefore, the experiment had 12 treatment combinations and 36 experimental units.

5.2.3. *Experimental procedures*

5.2.3.1. Harvesting and transportation of banana bunches

Banana bunches from cultivar ‘Poyo’, syn: ‘Robusta (*Musa* AAA Group, Cavendish Subgroup) were obtained from Jimma Agricultural Research Center, Jimma, Ethiopia. Fifteen matured bunches with light-green color and about three quarter full fingers were selected from the “Banana Variety Maintenance Trial” field. They were collected from prior selected and tagged plants that were healthy, robust and relatively uniform. Fruit bunches were carefully harvested late afternoon (4:00 to 5:00 p.m.) and carried on a shoulder pad of the harvesters and kept under natural tree shade for about one hour in order to stabilize them by minimizing the field heat. Bunches were then transported late afternoon to the Postharvest Department laboratory of JUCAVM.

5.2.3.2. Preparation of banana hands for 1-MCP treatment and packaging

Upon arrival at the Postharvest Department laboratory of JUCAVM, bunches were carefully unloaded and stabilized for two hours inside a ventilated room. They were then carefully de-handed in a cluster of five fingers per crown with a very sharp curved knife. Immediately after de-handing, any remaining flower residues were removed and the fruits were washed using 2% Sodium hypochlorite solution (NaClO) for 3 minutes and further rinsed in running clean tap water. Fruits were then air dried at room temperature and hands were brushed with ‘alum’ (astringent salt based on Aluminum Sulphate) to avoid any latent infection at the wounded sites.

5.2.3.3. Construction of 1-MCP treatment structure

Off-white High Density Polyethylene sheet (HDPE, 0.97 g/cm^3 or 970 kg/m^3 in density and 0.250 inch thickness) was used to construct the 2m*2m*1.5m (6m^3) sized airtight 1-MCP treatment chambers within a vacant room in the Department of Postharvest Management of JUCAVM (Figure 5.1). A small portable ventilation fan (Model: REE-NOVA FH-04: 220-240V/50~60Hz, China) was installed within each of the treatment chambers for uniform mixing and distribution of 1-MCP.

5.2.3.4. 1-MCP preparation and treatment

Smartfresh® powder, containing 0.14% 1-MCP active ingredient was used to release 1-MCP as per the procedures described by Erkan et al., (2004) and Morreti *et al*., (2002). Smartfresh® powder was precisely weighed to 250 mg, 150 mg and 50 mg which were then dissolved in 20 ml distilled water and heated to 50^{o}C to release the respective 1-MCP concentrations (17.5µl//L; 10.5µl/L and 3.5µl/L). Mixing of the solutions was carried out within the respective treatment chambers inside volumetric glass beakers closed with aluminum foil. After proper shaking of the solution, the beakers were opened and placed at the center of the respective chambers where the banana fruits were kept inside perforated plastic crates (Figure 4). Fruits were then withdrawn from the treatment chambers after 24 hours of exposure to 1-MCP.

Figure 4. Banana fruits being treated with 1-MCP within airtight chambers constructed using off-white transparent High Density Polyethylene (HDPE, 0.97 g/cm^3 in density and 0.250 inch thickness)

5.2.3.5. Withdrawal and placement of treated fruits into the packaging materials

A total of 36 export standard banana packaging materials were obtained from Ethio-Saudi International Agricultural PLC (MIDROC-Ethiopia Group S.C.). Forty five fruits of both the 1-MCP treated and untreated fruits were then assigned into each of the 36 packaging materials randomly placed across the laboratory benches as per the design layout of the experiment (Figure 5). They were kept under ambient conditions (23±1^{0}C and 73±1% RH) throughout the experimental period (36 days). Then 3-5 fruits were periodically taken at 7 days interval to examine the periodic changes on physicochemical quality attributes. The temperature and relative humidity of the display room was recorded three times a day (i.e. morning, mid-day and late afternoon) throughout the experimental period.

Figure 5. Bananas fruits stored within export standard corrugated cardboard boxes with and without inner low density polyethylene bags (LDPE, i.e. 0.91 g/cm^3 density and 0.038 mm thickness)

5.2.4. Data collected

Data collection was started right after the arrival of the fruits but just before the application of the 1-MCP treatments; regarded as day zero (Day 0). This was considered as a benchmark to evaluate the subsequent physicochemical changes over the whole storage period (Table 19). The remaining data were collected as of the first day after the treatment period (Day 1) and then continued at seven days interval up until the fruits display significant signs of basic quality losses in terms of the following physicochemical parameters.

Table 19. Benchmark measurements of physicochemical parameters taken during day zero (before 1-MCP treatment of fruits)

S.No.	Parameter	Values
1	Av. initial finger weight (g)	124
2	Av. initial weight of fruits (5 fingers) kept for % PWL analysis (g)	620
3	Firmness (N)	25.43
4	Peel color L*	13.72
5	Peel color a*	-13.24
6	Peel color b*	47.31
7	Color chart index	1 (All Green)
8	Starch un staining index	1 (< 5% un stained)
9	TSS (^{0}Brix)	3.2
10	TA (%)	0.21
11	TSS:TA	15.24
12	P^H	5.46
13	Pulp dry matter (%)	79.67

Note: Av. bunch wt=22.6 kg; Av. number of hands/bunch=10; Av. number of fingers/hand=17; Av. Length of fingers=19.4 cm

5.2.4.1. Physical parameters

Physiological weight loss (PWL %)

Physiological weight loss of fruits was assessed throughout the experimental period by periodic weighing of five sample fingers from each experimental unit using a precision scale (model: LS200 Sartorius GMBH Gottingen, Germany). PWL was calculated using Eq. 1.

$$Weight\ loss(\%) = \frac{Initial\ weight(g) - Final\ weight(g)}{Initial\ weight(g)} \times 100$$
……………………..Equation 1

Fruit firmness (N)

Fruit firmness was measured using a Texture Analyzer (Model: TA-XT Plus, UK) and calculated by employing the method used by Fan *et al.* (1999). Two whole unpeeled fingers were periodically randomly sampled from each experimental unit to measure the penetration force required at opposite sides of their equatorial axes by a stainless plunger. The exerted force was automatically recorded and expressed in Newton (N).

Fruit peel color

Peel color was measured alternatively using Dole Banana Color Guide (© 2004 Dole Fresh Fruit Company, Inc., USA, Figure 6) and the Tri-Stimulus Colorimeter (AccuProbe HH06, USA), which was regularly calibrated before measurement with a Minolta standard white tile to *L*=83.14, *a*=-3.67 and *b*=10.79. Total colour change (ΔE) of the sample fruits was determined using the CIE (Commission Internationale de L'Eclairage) 1976 *L*a*b color scale* system; where *L**scale measures lightness ('light vs. dark') and varies from 100 for perfect white to zero for perfect black; *a** measures redness ('red vs. green'), and *b** measures blue to yellowness. Total color change (ΔE) was calculated by using Eq. 2. (AOAC, 1984).

$$\Delta E = \sqrt{(L^*_i - L_f)^2 + (a^*_i - a_f)^2 + (b^*_i - b_f)^2} \quad \text{-----Equation 2}$$

Where:
i= initial, and f= final

Figure 6. "Dole Color Change Guide" for determining stages of banana ripening

5.2.4.2. Chemical parameters

Pulp starch content

Extent of starch staining was assessed after 3-5 minutes dipping of a cross-sectional cut of the unpeeled sample fruits in starch-iodine staining solution with10g potassium iodide (KI) and 2.5g iodine (I_2) in 250 ml distilled water. It was carried out as per the rapid starch staining method and chart developed by Saltveit *et al*. (1982) and Sylvia *et al*. (1993). The extent of staining on the sample banana fruits was then rated based on the chart developed previously into 10 distinguishable stages with rating numbers ranging from 1 to 10 based on the percentage of unstained area, i.e. 1 for <5% unstained area, 2 (5%), 3 (10%), 4 (15%), 5 (25%), 6 (35%), 7 (45%), 8 (55%), 9 (65%) and 10 (>65%). A trend of increase in the rating number, from 1 to 10, was expressed as a characteristic pattern of starch loss during ripening.

Total soluble solids-TSS (°Brix)

Sample fruits were peeled and blended using a juice blender and TSS of the pulp juice was measured by the refractive index, expressed as °Brix, by a portable hand Refractometer (Model: SN-003007). The macerated samples were homogenized by adding about 40 ml of distilled water and filtered with cheese cloth. One to two drops of the filtrate was then placed on to the glass prism of the refractometer for reading within the scale.

Titratable acidity (TA %)

Titratable acidity was measured by titrating the pulp filtrates with 0.1N NaOH solution with 2 to 5 drops of phenolphthalein until the indicator light pink color was depicted. The volume of NaOH used up was then recorded and TA was expressed as percentage of malic acid (Hewage, 1996) equivalent in the pulp weight of the titrate as calculated using Eq. 3.

$$\text{Titratable Acidity (\%)} = \frac{V1*N*E}{V2} \times 100 \quad \text{......Equation 3}$$

Where:

N = Normality of NaOH

V_1 = Volume of NaOH used

E = Equivalent weight of Acid

V_2 = Volume of sample taken for estimation

TSS:TA ratio

The ratios between total soluble solids and titratable acidity were determined by dividing the values of TSS to the values of TA of the same sample fruit.

Pulp pH

The pH of the sample fruit juice was measured using a bench top digital pH meter (model: CP-505, Poland).

Pulp dry matter content (DM %)

Dry matter content (DM %) in the pulp was determined according to the method of AOAC (2005). A 20 gram of the blended fruit juice was periodically taken into a calibrated petridish and placed in the digital oven (model: CP2 + 055F3030D19, UK) at 60^{o}C. Drying of the samples continued until the difference between the values of two consecutive measurements was not greater than 1 g. Weight of the samples was measured before and after oven drying using an electronic analytical balance (Model: PGW753 ABJ220-4M, Germany). Finally the dry matter content of the pulp was calculated using Eq. 4. (AOAC, 2005).

$$\text{Dry Matter (\%)} = \frac{\text{Final Dry Weight}}{\text{Initial Wet Weight}} \text{ x } 100 \qquad \text{Equation 4}$$

5.2.5. Statistical analysis

The experimental data were analyzed through the Analysis of Variance (ANOVA) by using GLM procedure of SAS software version 9.2. The Least Significant Differences (LSD %) test was used to determine the level of significance at 5% ($P < 0.05$) as well as for mean separation.

5.3. Results and Discussion

5.3.1. Physical parameters

Physiological weight loss (PWL %)

Statistically significant difference *($p \leq 0.05$)* on PWL was observed at different storage durations when fruits handled under different treatments. PWL was generally increased as the storage period prolonged irrespective of treatments (Table 20). The trend correspondingly showed strong positive correlations with peel color change (r=0.56), starch un staining (r=0.41), TSS (r=0.59), TA (r=0.34), and TSS:TA (r=0.48) as well as negative correlations with pH (r=-0.53) and firmness (r=-0.60) (Table 30). The two-way interaction effect between packaging materials and 1-MCP showed statistically significant ($p \leq 0.05$) effect on PWL throughout the storage period.

1-MCP treated fruits with increased concentrations from 10.5µl/L to 17.5µl/L and stored in corrugated cardboard boxes with inner non-perforated PEP (P1) exhibited significantly ($p \leq 0.05$) low weight loss (17.47-19.90%) at the end of 36 days long storage period. However, since the 17.5µl/L and 10.5µl/L concentrations of 1-MCP showed statistically non-significant ($p \leq 0.05$) differences, the lower concentration of 10.5µl/L could be considered economically more acceptable in terms of PWL reduction. The result was generally in line with similar studies reported by different authors (Sisler *et al*., 2003; Siriboon *et al*., 2004). The phenomena was similarly attributed to the property of 1-MCP in blocking the action of ethylene that has a direct relationship with respiration and fruit ripening. A similar phenomena on the effect of polyethylene packaging (PEP) on litchi fruits were reported that fruits exhibited less PWL on the 18th day of storage when kept in sealed or non-perforated PEP than those kept inside perforated PEP and totally unpackaged (De Reuck *et al*., 2009). This could be similarly attributed to the higher relative humidity, lower air movement around the fruits, and less oxygen depletion with subsequently less release of CO_2 created as a result of the modified atmosphere created within the non-perforated (P1) PEP (Sisler *et al*., 2003; De Reuck *et al*., 2009). De Reuck *et al.* (2009) also reported that integrated treatments of 1-MCP and modified atmosphere packaging (MAP) significantly ($p<0.001$) lower PWL than when the two factors were applied separately.

Conversely, the highest PWL loss (31.30%) was recorded for 1-MCP untreated fruits stored within the standalone corrugated cardboard boxes (P3), which at the same time lost their shelf life much faster (as of the 22nd day of storage) than the rest of the treatments. Likewise, this phenomena could be attributed to the fact that the ethylene triggered increase in respiration rate, as a result of the increase in metabolic process and membrane permeability, led the 1-MCP untreated fruits faster into deterioration with subsequent increase in respiratory water loss through the peel.

Table 20. Physiological weight loss (%) of banana fruits as affected by 1-MCP and packaging materials

Treatments	Storage Duration (Days)					
	1	8	15	22	29	36
P1 *17.5µl/L	2.10^{d}	6.53^{c}	8.10^{c}	9.30^{c}	15.70^{c}	17.47^{e}
P1 *10.5µl/L	3.90^{d}	12.03^{abc}	12.27^{bc}	13.67^{cd}	18.50^{c}	19.90^{e}
P1 *3.5µl/L	5.50^{cd}	14.67^{abc}	16.40^{abc}	16.60^{bcd}	26.13^{b}	31.23^{bc}
P1 *Untreated	9.80^{bcd}	16.10^{abc}	19.63^{abc}	20.17^{bcd}	-	-
P2 *17.5µl/L	2.23^{d}	10.47^{bc}	12.00^{bc}	15.67^{bcd}	21.25^{bc}	24.73^{d}
P2 *10.5µl/L	10.63^{bcd}	12.97^{abc}	15.07^{abc}	17.07^{bcd}	27.78^{b}	28.50^{c}
P2 *3.5µl/L	14.03^{abc}	16.50^{abc}	18.13^{abc}	19.80^{bcd}	27.45^{b}	32.40^{b}
P2 *Untreated	19.60^{a}	20.63^{ab}	20.90^{ab}	24.27^{abc}	-	-
P3 *17.5µl/L	2.30^{d}	10.87^{abc}	18.03^{abc}	19.83^{bcd}	25.48^{b}	27.70^{cd}
P3 *10.5µl/L	6.40^{bcd}	13.20^{abc}	18.83^{abc}	26.00^{ab}	36.92^{a}	43.53^{a}
P3 *3.5µl/L	14.10^{ab}	18.23^{ab}	20.73^{ab}	26.43^{ab}	40.47^{a}	43.87^{a}
P3 *Untreated	20.57^{a}	20.63^{ab}	24.93^{a}	31.30^{a}	-	-
LSD (5%)	8.57	11.61	12.05	11.12	6.92	3.55
SE (±)	5.06	6.85	7.12	6.57	5.94	2.05
CV (%)	54.62	47.10	41.64	32.82	22.30	6.85

* In each column, means followed by the same letter (s) are not significantly different by Least Significant Difference (LSD) test at p ≤ 0.05; **P1=** Export standard cardboard boxes with non-perforated PEP; **P2=** Export standard cardboard boxes with perforated PEP **P3=** Standalone export standard cardboard boxes (without inner PEP)

Firmness (N)

Results on fruit firmness generally revealed a decreasing trend over the storage period irrespective of treatments (Table 21). The trend also demonstrated strong negative correlations with total peel color change (r=-0.71), starch unstaining (r=-0.58), TSS (r=-0.65), TA (r=-0.28), PWL (-0.60) and TSS/TA ration (r=-0.56), color index (r=-0.56) as well as positive correlation with pH (r=0.58) and pulp dry matter (r=-0.51) (Table 30). Statistically significant (*p ≤ 0.05)* interaction effects between the two factors were observed throughout the storage period. Fruits treated with the highest concentration of 1-MCP (17.5µl/L) maintained significantly *(p ≤ 0.05)* higher firmness (18.67N) during the last day of the storage period (day 36) when stored in combination with the non-perforated PEP (P1). On the contrary, the highest loss in firmness (14.80 N) with all treatment combinations were recorded for 1-MCP untreated fruits stored within the standalone corrugated cardboard boxes (P3), which at the same time lost their shelf life much faster (as of the 22ndday of storage) than the rest of the treatments.

The results were generally in agreement with several findings that 1-MCP treated banana fruits maintained higher firmness over various storage periods than their equivalent untreated ones (Mattheis, 2003; Lohani *et al*., 2004; Watkins, 2006; Zeweter *et al*., 2012). This was attributed to the inhibitory action of 1-MCP on ethylene synthesis and action by way of its irreversible binding ability to the receptors. De Reuck *et al*. (2009) also reported that the integrated application of 1-MCP and modified atmosphere packaging (MAP) using sealed or non-perforated PEP maintained significantly higher ($p<0.00$) firmness of litchi fruits than when the two factors were applied separately. This was similarly attributed to the strong modified atmosphere condition created within the overall sealed package which resulted in lower rate of respiration, reduction in fruit tissue breakdown and delay in the onset of ripening. Softening and the parallel increase in respiration rate in climacteric fruit ripening is generally attributed to several ultra structural and chemical metabolic changes and the de novo synthesis of cell wall hydrolases that result in the degradation of the cell wall, solubilization of pectins and movement of water from the peel to the pulp through osmotic pressure (Lohani *et al*., 2004; Dharmasenal *et al*., 2005).

Table 21. Firmness (N) of banana fruits as affected by 1-MCP and packaging materials

Treatments	Storage Duration (Days)					
	1	8	15	22	29	36
P1 *17.5µl/L	25.90^{a}	23.93^{a}	22.90^{a}	20.47^{a}	18.93^{a}	18.67^{a}
P1 *10.5µl/L	24.77^{ab}	23.23^{ab}	21.27^{ab}	20.00^{a}	16.20^{ab}	15.60^{ab}
P1 *3.5µl/L	23.87^{bc}	21.57^{bc}	20.53^{bc}	19.67^{a}	15.85^{b}	14.77^{ab}
P1 *Untreated	22.00^{de}	21.53^{bc}	20.57^{bc}	17.33^{ab}	-	-
P2 *17.5µl/L	23.00^{bcd}	21.50^{bc}	20.93^{abc}	20.30^{a}	16.65^{ab}	15.90^{ab}
P2 *10.5µl/L	22.77^{cd}	21.37^{bcd}	20.70^{b}c	19.80^{a}	16.02^{ab}	15.20^{ab}
P2 *3.5µl/L	22.43^{cde}	20.90^{cd}	20.17^{bc}	19.10^{a}	15.22^{bc}	12.07^{bc}
P2 *Untreated	20.77^{ef}	19.33^{cd}	18.80^{cd}	15.87^{b}	-	-
P3 *17.5µl/L	22.13^{cde}	20.63^{cd}	20.27^{bc}	19.97^{a}	16.38^{ab}	15.47^{ab}
P3 *10.5µl/L	21.77^{de}	20.57^{cd}	20.03^{bc}	19.60^{a}	15.42^{bc}	14.53^{bc}
P3 *3.5µl/L	21.43^{de}	20.40^{cd}	19.17^{bcd}	17.67^{ab}	12.72^{c}	10.57^{c}
P3 *Untreated	19.30^{f}	19.17^{d}	17.53^{d}	14.80^{b}	-	-
LSD (5%)	1.85	2.30	2.16	3.21	2.95	4.10
SE ($\pm$)	1.09	1.36	1.28	1.90	2.54	2.37
CV (%)	4.86	6.43	6.31	10.13	15.91	16.06

* In each column, means followed by the same letter (s) are not significantly different by Least Significant Difference (LSD) test at $p \leq 0.05$; **P1=** Export standard cardboard boxes with non-perforated PEP; **P2=** Export standard cardboard boxes with perforated PEP **P3=** Standalone export standard cardboard boxes (without inner PEP)

Peel color

The obvious manifestations of the banana fruits during the storage period in terms of the gradual decline of the green peel color were clearly observed in the present experiment with different intensities across the different treatments regimes (Tables 22and 23).

Results for both the total peel color change (ΔE) and color index (Tables 22and 23) indicate that there was significant (*$p \leq 0.05$)* interaction effect between 1-MCP application and packaging treatments. The highest concentration of 1-MCP (17.5 µl/L) when combined with the non-perforated PEP (P1) maintained the lowest peel color change (34.33 in ΔE and 1.67 in color index) at the end of the 36 days long storage period. Similarly, peel color change (52.27 in ΔE and 6.00 in color index) with all treatment combinations were recorded for 1-MCP untreated fruits stored within the standalone corrugated cardboard boxes (P3) on the 22nd day of the storage period.

The results basically agreed with previous findings of Moretti1 *et al*. (2002) that treatments with higher concentrations of 1-MCP delayed total carotenoids synthesis and color development and thus extended shelf life in tomato fruits. Results also concurred with other reports that the delay in banana peel color change could be attributed to the combined effect of the modified atmosphere *(*MA) condition created within the packages as a result of the fully sealed or non-perforated inner PEP (P1) as well as the direct inhibitory action of 1-MCP on both the synthesis and action of ethylene (Siriboon *et al*., 2004; Bassetto *et al*., 2005; Dharmasenal *et al*., 2005 Salvador *et al.* 2006). This signifies the fact that the respiration rate of fruits was restricted and thus the change in peel color was retarded as a result. The highest and fastest peel color change observed on fruits that were not treated with 1-MCP and kept inside the standalone corrugated cardboard boxes (P3), was similarly substantiated by Wills *et al*. (2000) and Pinto *et al*. (2004). Such fruits could possibly have more access to O_2 and more exposure to increases in the concentration of ethylene, which subsequently enhanced the respiration rate, chlorophyll degradation and ultimately the conversion of the green peel color into yellow.

Table 22. Total peel color change of banana fruits as affected by 1-MCP and packaging materials

Treatments	Storage Duration (Days)					
	1	8	15	22	29	36
P1 *17.5µl/L	4.77^{d}	13.63^{c}	20.40^{c}	23.47^{c}	33.68^{c}	34.33^{b}
P1 *10.5µl/L	8.60^{cd}	14.77^{bc}	23.97^{bc}	32.93^{abc}	37.60^{c}	43.17^{ab}
P1 *3.5µl/L	17.83^{abcd}	25.53^{abc}	31.47^{abc}	36.03^{abc}	56.88^{ab}	60.60^{ab}
P1 *Untreated	22.33^{abc}	32.07^{ab}	38.70^{abc}	43.27^{abc}	-	-
P2 *17.5µl/L	6.93^{cd}	18.80^{bc}	21.90^{c}	28.43^{bc}	39.65^{c}	40.83^{ab}
P2 *10.5µl/L	10.60^{bcd}	20.07^{bc}	30.23^{abc}	35.70^{abc}	39.82^{bc}	43.23^{ab}
P2 *3.5µl/L	22.07^{abc}	29.83^{abc}	34.30^{abc}	40.70^{abc}	59.80^{a}	62.70^{ab}
P2 *Untreated	27.00^{ab}	38.17^{a}	44.30^{ab}	48.00^{ab}	-	-
P3 *17.5µl/L	9.23^{cd}	19.30^{bc}	29.13^{abc}	29.37^{abc}	41.80^{bc}	41.67^{ab}
P3 *10.5µl/L	15.87^{abcd}	23.83^{abc}	30.60^{abc}	36.73^{abc}	50.33^{abc}	52.53^{ab}
P3 *3.5µl/L	22.23^{abc}	30.07^{abc}	34.33^{abc}	40.90^{abc}	65.22^{a}	66.80^{a}
P3 *Untreated	30.70^{a}	38.40^{a}	46.33^{a}	52.27^{a}	-	-
LSD (5%)	17.07	17.86	22.20	23.08	17.08	29.56
SE (+)	10.08	10.54	13.11	13.63	14.67	17.08
CV (%)	61.06	41.56	40.78	36.52	31.08	34.47

* In each column, means followed by the same letter (s) are not significantly different by Least Significant Difference (LSD) test at $p \leq 0.05$; **P1=** Export standard cardboard boxes with non-perforated PEP; **P2=** Export standard cardboard boxes with perforated PEP **P3=** Standalone export standard cardboard boxes (without inner PEP)

Table 23. Peel color index of banana fruits as affected by 1-MCP and packaging materials

Treatments	Storage Duration (Days)					
	1	8	15	22	29	36
P1 *17.5µl/L	1.33	1.34	1.37^{c}	1.38^{e}	1.50^{f}	1.67^{e}
P1 *10.5µl/L	1.33	1.68	2.00^{cb}	2.33^{ed}	2.50^{e}	2.67^{d}
P1 *3.5µl/L	1.67	1.69	2.33^{cb}	3.33^{cbd}	4.83^{c}	5.53^{bc}
P1 *Untreated	1.67	1.69	2.67^{b}	4.00^{cb}	-	-
P2 *17.5µl/L	1.33	1.33	1.33^{c}	1.33^{e}	1.50^{f}	1.69^{e}
P2 *10.5µl/L	1.67	1.68	2.33^{cb}	2.33^{ed}	3.33^{d}	3.33^{d}
P2 *3.5µl/L	1.67	1.69	2.67^{b}	4.33^{b}	5.50^{b}	5.67^{ba}
P2 *Untreated	1.67	1.69	4.33^{a}	6.00^{a}	-	-
P3 *17.5µl/L	1.33	1.34	1.67^{cb}	1.67^{e}	2.50^{e}	2.67^{d}
P3 *10.5µl/L	1.67	1.68	2.67^{b}	3.00^{cd}	4.50^{c}	4.67^{c}
P3 *3.5µl/L	1.67	1.69	2.67^{b}	4.33^{b}	6.33^{a}	6.33^{a}
P3 *Untreated	1.67	1.69	4.67^{a}	6.00^{a}	-	-
LSD (5%)	0.83	0.79	1.01	1.06	0.44	0.76
SE (+)	0.49	0.47	0.59	0.63	0.38	0.44
CV (%)	30.40	29.60	23.27	18.83	10.39	11.67

* In each column, means followed by the same letter (s) are not significantly different by Least Significant Difference (LSD) test at $p \leq 0.0.$; **P1=** Export standard cardboard boxes with non-perforated PEP; **P2=** Export standard cardboard boxes with perforated PEP **P3=** Standalone export standard cardboard boxes (without inner PEP)

Note: 1=All Green; 2=Light Green; 3=50% Green: 50% Yellow; 4=More Yellow than Green; 5=Yellow with Green Tips; 6=Fully Yellow; and 7=Yellow Flecked with Brown

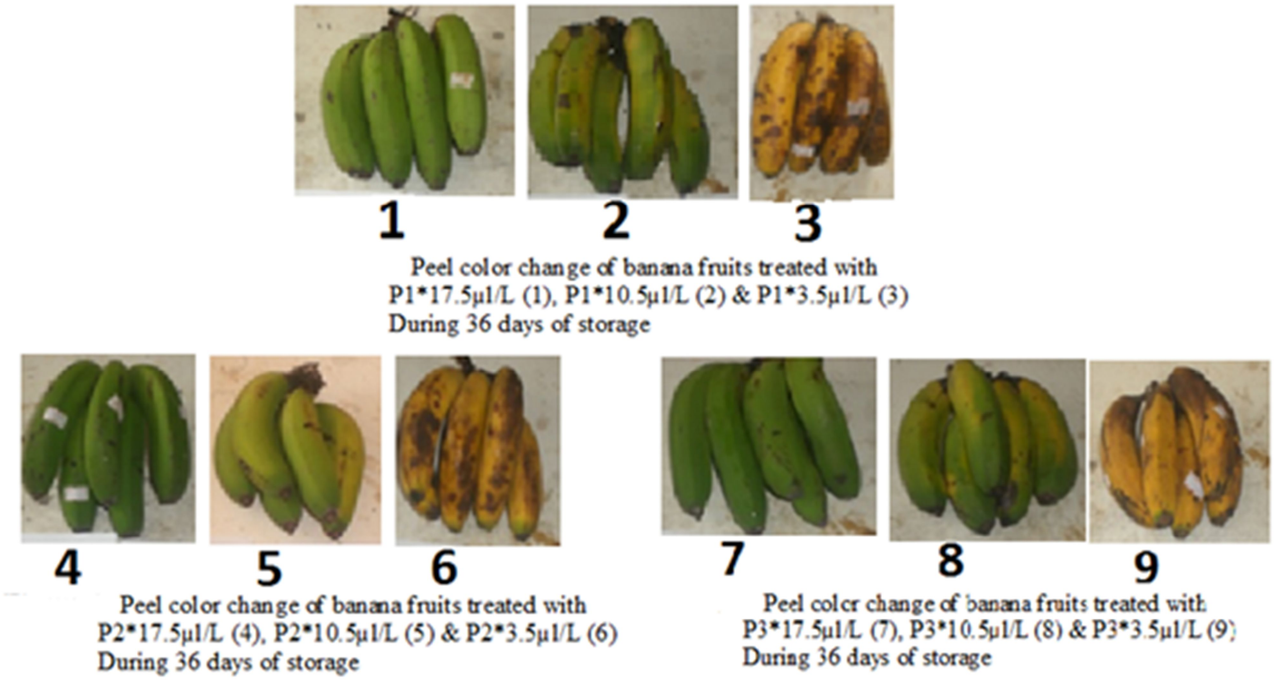

Figure 7. Combined effects of 1-MCP concentrations and export standard packaging materials on peel color change of banana fruits stored for 36 days under ambient conditions (23 ± 1^0C and 73±1% RH)

5.3.2. Chemical characteristics

Pulp starch content

Significant differences *($p \leq 0.05$)* in starch unstaining was observed on fruits stored under different treatments (Table 24).A blue-blackcolor due to starch staining was observed more on unripe fruits than those that have lost their starch content due to the ripening process. The proportion of starch stained area was slightly but consistently decreased over the storage period irrespective of treatments. This trend of gradual decrease in starch staining could be attributed to the corresponding increase in the hydrolysis of starch into simple sugars. The results were also supported by reports of previous findings that starch hydrolysis is a very important postharvest biochemical change which occurs during the ripening process of banana fruits and causes the accumulation of sugar that are responsible for the increase in pulp TSS content and sweetening of the fruit (Tourky *et al*., 2014).

Results also showed that there was significant *($p \leq 0.05$)* interaction effect between 1-MCP and packaging treatments in starch unstaining throughout the 36 days storage period. Banana fruits treated interactively with the highest concentration of 1-MCP (17.5µl/L) and non-perforated PEP (P1) showed the lowest proportion of starch unstaining (1.73) at the end of the 36 days long storage period. The results were in agreement with the report of Jiang *et al*. (2004) that the greatest longevity of about 58 days was realizedwith 1-MCP treated banana fruits (at either of 0.5 or 1.0 µl/l) and kept inside sealed polyethylene bags (0.03 mm thick) due to the suppression of ethylene (C_2H_4) evolution, reduced rate of respiration, reduced rate of starch hydrolysis into simple sugars, and delayed ripening.

The highest level of starch unstaining was exhibited by 1-MCP untreated (9.33) fruits that were kept inside the standalone corrugated cardboard boxes (P3). This is an indication of high rate of respiration and the subsequent onset of the climacteric peak and ripening stage that brought about a more rapid deterioration in the shelf life of banana fruits (Hernandez *et al*., 2006).

Table 24. Pulp starch unstaining index of banana fruits as affected by 1-MCP and packaging materials

Treatments	Storage Duration (Days)					
	1	8	15	22	29	36
P1 *17.5µl/L	1.33^{b}	1.33^{e}	1.33^{f}	1.67^{g}	1.73^{e}	1.73^{d}
P1 *10.5µl/L	1.33^{b}	1.33^{e}	1.67^{ef}	2.33^{f}	4.33^{d}	5.33^{c}
P1 *3.5µl/L	1.33^{b}	1.67^{e}	2.00^{ed}	4.33^{e}	8.17^{b}	10.00^{a}
P1 *Untreated	2.33^{a}	3.33^{c}	3.33^{c}	6.33^{d}	-	-
P2 *17.5µl/L	1.33^{b}	1.33^{e}	1.33^{f}	1.67^{g}	2.33^{e}	2.33^{d}
P2 *10.5µl/L	1.33^{b}	1.67^{e}	1.67^{ef}	2.33^{f}	5.33^{cd}	6.33^{b}
P2 *3.5µl/L	1.67^{b}	1.67^{e}	2.33^{d}	6.33^{d}	9.67^{a}	10.00^{a}
P2 *Untreated	2.33^{a}	4.33^{b}	5.33^{a}	8.33^{b}	-	-
P3 *17.5µl/L	1.33^{b}	1.33^{e}	1.33^{f}	2.00^{gf}	2.33^{e}	2.33^{d}
P3 *10.5µl/L	1.67^{b}	1.67^{e}	1.67^{ef}	2.33^{f}	6.33^{c}	6.33^{b}
P3 *3.5µl/L	1.67^{b}	2.33^{d}	4.33^{b}	7.67^{c}	9.67^{a}	10.00^{a}
P3 *Untreated	2.67^{a}	5.33^{a}	5.33^{a}	9.33^{a}	-	-
LSD (5%)	0.54	0.54	0.54	0.50	1.05	0.50
SE ($\pm$)	0.32	0.32	0.32	0.30	0.90	0.29
CV (%)	18.99	14.13	12.19	6.53	17.13	5.00

* In each column, means followed by the same letter (s) are not significantly different by Least Significant Difference (LSD) test at $p \leq 0.05$; P1= Export standard cardboard boxes with non-perforated PEP; **P2=** Export standard cardboard boxes with perforated PEP **P3=** Standalone export standard cardboard boxes (without inner PEP)

TSS (^{0}Brix)

Table 25 shows that Total Soluble Solids (TSS) content was, gradually but consistently, increased throughout the storage period irrespective of treatments. The results are generally in agreement with previous findings that the amount of sugars usually increases along with fruit ripening through biosynthesis processes or degradation of polysaccharides (Bassetto *et al*., 2005).

Results also showed that there was significant *($p \leq 0.05$)* interaction effect between 1-MCP and packaging treatments throughout the 36 days long storage period. The highest TSS (9.57 ^{0}Brix) was recorded on the 22nd day of the storage period from 1-MCP untreated fruits that kept inside the standalone corrugated cardboard boxes without inner PEP (P3). This could be an indication of the rapid deterioration in shelf life of the fruits as a result of the onset and progress of the climacteric peak caused by the higher rate of respiration (Hernandez *et al*., 2006). The lowest TSS (8.00 ^{0}Brix) at the end of the 36 days long storage period was, on the contrary, recorded from fruits treated with the highest concentration of 1-MCP (17.5µl/L) and kept inside the non-perforated inner PEP (P1). This could also be due to the reduced rate of starch hydrolysis into simple sugars and delayed ripening. Ethylene biosynthesis has two stages namely oxygen dependent and independent stages. The conversion of ACC (1-Aminocyclopropane carboxylic acid) to Ethylene is catalyzed by ACC oxidase which requires oxygen. Thus, the lack of perforation in PEP might have limited the amount of oxygen, which in turn retarded ethylene biosynthesis and ripening. Lower amounts of TSS in fruits treated with 1-MCP were also verified in other studies (Watkins *et al*., 2000; Bassetto *et al*., 2005).

Table 25. Total Soluble Solids (^{0}Brix) of banana fruits as affected by 1-MCP and packaging materials

Treatments	Storage Duration (Days)					
	1	8	15	22	29	36
P1 *17.5µl/L	6.07^{b}	6.23^{c}	6.60^{e}	6.90^{d}	7.70^{c}	8.00^{g}
P1 *10.5µl/L	6.20^{b}	6.30^{c}	6.70^{e}	7.00^{d}	9.37^{bc}	10.07^{e}
P1 *3.5µl/L	6.23^{b}	6.40^{c}	6.80^{de}	8.13^{bcd}	11.20^{b}	12.33^{c}
P1 *Untreated	6.23^{b}	6.40^{c}	6.97^{cde}	8.60^{abc}	-	-
P2 *17.5µl/L	6.10^{b}	6.30^{c}	6.67^{e}	7.00^{d}	9.10^{bc}	9.20^{f}
P2 *10.5µl/L	6.20^{b}	6.30^{c}	7.40^{bcd}	7.87^{dc}	10.23^{bc}	10.93^{d}
P2 *3.5µl/L	6.23^{b}	6.47^{bc}	7.43^{bcd}	8.70^{abc}	11.47^{b}	13.00^{b}
P2 *Untreated	6.63^{a}	6.87^{ab}	8.00^{ab}	9.47^{a}	-	-
P3 *17.5µl/L	6.20^{b}	6.33^{c}	6.67^{e}	7.00^{d}	10.17^{bc}	10.53^{d}
P3 *10.5µl/L	6.23^{b}	6.37^{c}	7.50^{bc}	9.00^{abc}	11.15^{b}	12.20^{c}
P3 *3.5µl/L	6.27^{b}	6.53^{bc}	7.93^{ab}	9.33^{ab}	14.97^{a}	20.33^{a}
P3 *Untreated	6.67^{a}	7.00^{a}	8.37^{a}	9.57^{a}	-	-
LSD (5%)	0.32	0.43	0.64	1.28	2.61	0.41
SE (+)	0.19	0.25	0.38	0.75	2.24	0.24
CV (%)	2.98	3.94	5.21	9.17	21.19	2.01

* In each column, means followed by the same letter (s) are not significantly different by Least Significant Difference (LSD) test at $p \leq 0.05$; P1= Export standard cardboard boxes with non-perforated PEP; **P2=** Export standard cardboard boxes with perforated PEP **P3=** Standalone export standard cardboard boxes (without inner PEP)

Titratable Acidity (TA %)

Although the percentage values were recorded in a narrow range, a progressive increase up until the 22nd day and then a gradual decline as of the 29th day of the storage period was observed with titratable acidity (TA) in all treatments (Table 26). Similar results were also reported by Zeweter *et al*. (2012) that TA content in banana fruits treated with 1-MCP was increased as the storage period progressed from 4 to 28 days and slightly declined towards the end.

Our statistical analysis indicates that there was significant ($p \leq 0.05$) interaction effect between 1-MCP and packaging treatments on TA of banana fruits from day one to the 22nd day of the storage period. The overall trend across the 36 days storage period showed that changes in TA content were lower (0.29 %) when fruits were treated with the highest concentrations of 1-MCP (10.5µl/L- 17.5µl/L) and stored inside non-perforated PEP (P1). This could be similarly attributed to the combined effect of the modified atmosphere (MA) condition created within sealed or non-perforated packages coupled with the direct inhibition of 1-MCP on both the production and action of ethylene (Siriboon *et al*. 2004; Bassetto *et al*., 2005; Dharmasenal *et al*., 2005; Salvador *et al*. 2006). Organic acids, like malic acid in banana, can serve as substrates for respiration. However, the rate of respiration is higly influenced, in addition to the concentration of substrates, by the level of oxygen concentration and temperature during storage. This may also signify the fact that the respiration rate of the fruits was retarded consequently and thus rate of utilization of the respiratory substrates such as organic acids was so minimal in this case. Kader (1992) similarly stated that lower fruit acidity due to postharvest treatments that delay respiration could be a result of a reduced utilization rate of respiratory substrates such as organic acids.

Table 26. Titratable acidity (%) of banana fruits as affected by 1-MCP and export standard packaging materials

Treatments	Storage Duration (Days)					
	1	8	15	22	29	36
P1 *17.5µl/L	0.30^{b}	0.31^{b}	0.32^{c}	0.33^{bc}	0.31	0.29
P1 *10.5µl/L	0.30^{ab}	0.32^{ab}	0.32^{c}	0.33^{abc}	0.32	0.29
P1 *3.5µl/L	0.31^{ab}	0.32^{ab}	0.33^{abc}	0.33^{c}	0.33	0.32
P1 *Untreated	0.31^{ab}	0.32^{ab}	0.33^{abc}	0.35^{a}	-	-
P2 *17.5µl/L	0.30^{ab}	0.32^{ab}	0.32^{bc}	0.34^{abc}	0.32	0.30
P2 *10.5µl/L	0.31^{ab}	0.32^{ab}	0.33^{abc}	0.34^{abc}	0.33	0.31
P2 *3.5µl/L	0.31^{ab}	0.32^{ab}	0.33^{abc}	0.34^{abc}	0.33	0.32
P2 *Untreated	0.32^{ab}	0.33^{a}	0.34^{ab}	0.35^{ab}	-	-
P3 *17.5µl/L	0.31^{ab}	0.32^{ab}	0.33^{abc}	0.34^{abc}	0.33	0.31
P3 *10.5µl/L	0.31^{ab}	0.32^{ab}	0.33^{abc}	0.34^{abc}	0.33	0.31
P3 *3.5µl/L	0.31^{ab}	0.33^{a}	0.33^{abc}	0.34^{abc}	0.34	0.32
P3 *Untreated	0.32^{a}	0.33^{a}	0.34^{a}	0.35^{ab}	-	-
LSD (5%)	0.02	0.02	0.02	0.02	0.03	0.03
SE (±)	0.01	0.01	0.01	0.01	0.03	0.02
CV (%)	3.92	3.57	2.88	3.98	7.86	6.51

* In each column, means followed by the same letter (s) are not significantly different by Least Significant Difference (LSD) test at p ≤ 0.05; P1= Export standard cardboard boxes with non-perforated PEP; **P2=** Export standard cardboard boxes with perforated PEP **P3=** Standalone export standard cardboard boxes (without inner PEP)

TSS: TA ratio

The sugar to acid ratio, which is often considered as a ripening index (RI), determines the sugar-acid balance of the ripening fruits. It is also known as one of the postharvest quality attributes that influence the perception of consumers. In the present experiment, statistically significant differences *(p ≤ 0.05)* were observed in the sugar to acid ratio of banana fruits stored under different treatments. TSS:TA ratio was generally increased throughout the storage period across all treatments (Table 27).

Interaction effects between treatments of 1-MCP and packaging materials showed significant *(p ≤ 0.05)* differences across the 36 days long storage period. The lowest sugar to acid ratio (27.67) was similarly recorded at the end of the storage period from fruits treated with the highest concentration of 1-MCP (17.5µl/L) and kept inside non-perforated inner PEP (P1). On the other hand, the highest sugar to acid ratio (28.44) was recorded on the 22nd day of the storage period from 1-MCP untreated fruits kept in the standalone corrugated cardboard boxes (P3). The phenomena in the later case is tantamount to the increase in respiration rate and oxidation as the storage period proceeded, increase in the subsequent utilization of the respiratory substrates such as organic acids, and increase in starch hydrolysis and accumulation of simple sugars in the event of the fruit ripening process with subsequent decline in shelf life (Macwan *et al*., 2014).

Table 27. TSS:TA ratio of banana fruits as affected by 1-MCP and export standard packaging materials

Treatments	Storage Duration (Days)					
	1	8	15	22	29	36
P1 *17.5µl/L	18.70^{d}	18.98^{d}	19.80^{e}	20.60^{d}	24.95^{c}	27.67^{e}
P1 *10.5µl/L	19.49^{cd}	19.70^{cd}	20.87^{cde}	21.05^{d}	28.69^{bc}	31.85^{cde}
P1 *3.5µl/L	19.76^{bcd}	20.26^{bcd}	21.14^{cde}	23.01^{cd}	34.97^{bc}	41.76^{b}
P1 *Untreated	20.10^{bcd}	20.35^{bcd}	21.26^{cde}	26.40^{abc}	-	-
P2 *17.5µl/L	18.97^{cd}	19.36^{cd}	19.90^{e}	20.80^{d}	27.97^{bc}	29.95^{de}
P2 *10.5µl/L	19.72^{bcd}	19.92^{bcd}	22.11^{cd}	23.41^{cd}	31.03^{bc}	34.54^{c}
P2 *3.5µl/L	20.30^{abcd}	20.48^{abcd}	22.47^{bc}	24.87^{bc}	36.10^{b}	42.16^{b}
P2 *Untreated	21.34^{ab}	21.50^{ab}	24.74^{a}	28.13^{ab}	-	-
P3 *17.5µl/L	19.81^{bcd}	19.81^{bcd}	20.25^{de}	20.92^{d}	30.57^{bc}	33.06^{cd}
P3 *10.5µl/L	19.94^{bcd}	20.57^{abc}	22.32^{c}	25.78^{abc}	34.78^{bc}	40.11^{b}
P3 *3.5µl/L	20.70^{abc}	20.94^{abc}	24.38^{ab}	27.71^{ab}	48.26^{a}	68.54^{a}
P3 *Untreated	21.94^{a}	22.27^{a}	25.72^{a}	28.44^{a}	-	-
LSD (5%)	1.56	1.98	2.01	3.46	10.58	4.28
SE (±)	0.92	1.17	1.19	2.04	9.09	2.47
CV (%)	4.53	5.82	5.38	8.41	27.50	6.37

* In each column, means followed by the same letter (s) are not significantly different by Least Significant Difference (LSD) test at p ≤ 0.05; P1= Export standard cardboard boxes with non-perforated PEP; **P2=** Export standard cardboard boxes with perforated PEP **P3=** Standalone export standard cardboard boxes (without inner PEP)

pH

Table 28 below shows that the P^{H} of the fruit pulp generally decreased steadily over the storage period irrespective of treatments. The results are in agreement with the findings reported by Tourky *et al*. (2014) in that as the storage period or ripening process advances, total acidity could increase resulting in a decrease in fruit pH. A similar result was reported by Hernandez *et al*. (2006) that as the storage period progresses, the evolution of ethylene and respiration rate may increase with a subsequent decrease in pulp pH.

Results also show that there was significant ($p < 0.05$) interaction effect between 1-MCP and packaging treatments on the pH of banana fruits throughout the 36 days long storage period.
Fruits treated with the highest concentration of 1-MCP (17.5µl/L) and stored in combination with non-perforated PEP (P1) maintained the highest pH (4.13) at the end of the storage period.

This concurs with previous reports that the inhibitory action of 1-MCP on ethylene production and action in combination with the higher modified atmosphere condition createdas a result of the non-perforated PEP might have created a reduction in the rate of respiration and overall metabolic process of the fruits (Jobling, 2000; Mattheis *et al.,* 2003).

Table 28. Pulp pH of banana fruits as affected by 1-MCP and export standard packaging materials

Treatments	Storage Duration (Days)					
	1	8	15	22	29	36
P1 *17.5µl/L	5.40^{a}	5.37^{a}	5.30^{a}	5.20^{a}	4.63^{a}	4.13^{a}
P1 *10.5µl/L	5.37^{ab}	5.37^{a}	5.23^{ab}	5.17^{a}	3.87^{ab}	3.03^{ab}
P1 *3.5µl/L	5.33^{ab}	5.27^{ab}	5.17^{ab}	5.03^{ab}	3.62^{ab}	2.63^{b}
P1 *Untreated	5.30^{b}	5.27^{ab}	5.10^{ab}	4.33^{ab}	-	-
P2 *17.5µl/L	5.40^{a}	5.33^{ab}	5.23^{ab}	5.17^{a}	3.80^{ab}	3.33^{ab}
P2 *10.5µl/L	5.33^{ab}	5.30^{ab}	5.17^{ab}	5.10^{ab}	3.72^{ab}	2.63^{b}
P2 *3.5µl/L	5.33^{ab}	5.27^{ab}	5.10^{ab}	4.87^{ab}	3.42^{ab}	2.57^{b}
P2 *Untreated	5.30^{b}	5.23^{b}	5.07^{ab}	4.30^{b}	-	-
P3 *17.5µl/L	5.40^{a}	5.30^{ab}	5.23^{ab}	5.03^{ab}	3.78^{ab}	3.30^{ab}
P3 *10.5µl/L	5.33^{ab}	5.27^{ab}	5.17^{ab}	4.90^{ab}	3.45^{ab}	2.60^{b}
P3 *3.5µl/L	5.33^{ab}	5.23^{b}	5.10^{ab}	4.37^{ab}	3.00^{b}	2.53^{b}
P3 *Untreated	5.30^{b}	5.23^{b}	5.03^{ab}	4.20^{b}	-	-
LSD (5%)	0.10	0.11	1.00	0.93	1.45	1.43
SE (±)	0.06	0.06	0.59	0.55	1.25	0.82
CV (%)	1.05	1.18	11.72	11.20	33.74	27.73

* In each column, means followed by the same letter (s) are not significantly different by Least Significant Difference (LSD) test at $p \leq 0.05$; P1= Export standard cardboard boxes with non-perforated PEP; **P2=** Export standard cardboard boxes with perforated PEP **P3=** Standalone export standard cardboard boxes (without inner PEP)

Pulp dry matter content (%)

Pulp dry matter is basically a reverse of the pulp moisture content in that as the later increases with the advance in the storage or ripening period, as a result of carbohydrate breakdown and moisture migration through osmotic pressure from the peel to the pulp, percent dry matter correspondingly decreases (Sarode *et al*., 2009; Kurmani *et al*., 2010; Tourky *et al*., 2014). Likewise, the data in Table 29 illustrates that the pulp dry matter of banana fruits steadily decreased over the storage period irrespective of treatments.

Interaction effects of 1-MCP and packaging on dry matter content of the fruit pulp showed significant ($p < 0.05$) differences throughout the storage period. The highest percentage (70.50%) of dry matter content was recorded at the end of the 36 days storage period from banana fruits treated with the highest concentration of 1-MCP (17.5µl/L) and kept inside the non-perforated PEP (P1). This shows a greater delay in the degradation of dry matter content of the fruits corresponding to the extension in shelf life of banana fruits. This is similarly attributed to the higher modified atmosphere condition createdbythe non-perforated PEP, which resulted in a greater reduction in the rate of respiration and overall metabolic process of the fruits (Jobling, 2000; Mattheis *et al*., 2003). On the other hand, the lowest percentage of dry matter (69.13%) was recorded on the 22nd day of the storage period from 1-MCP untreated fruits and kept within the standalone corrugated cardboard boxes (P3). Such a rapid decline in pulp dry matter content could beattributed to the increase in pulp TSS as a result of the continued starch hydrolysis into simple soluble sugars (Patil *et al*., 2015).

Table 29. Pulp dry matter content (%) of banana fruits as affected by 1-MCP and packaging materials

Treatments	StorageDuration (Days)					
	1	8	15	22	29	36
P1 *17.5µl/L	29.50^{a}	28.80^{a}	24.20^{a}	23.67^{a}	22.60^{a}	21.20^{a}
P1 *10.5µl/L	39.73^{ab}	34.07^{ab}	26.07^{ab}	24.77^{ab}	24.27^{ab}	21.37^{a}
P1 *3.5µl/L	40.27^{abc}	38.18^{abc}	26.47^{ab}	25.60^{abc}	24.47^{ab}	23.40^{a}
P1 *Untreated	41.18^{abc}	39.16^{abc}	27.40^{bc}	25.73^{abc}	24.83^{ab}	24.10^{a}
P2 *17.5µl/L	42.87^{abcd}	39.70^{abc}	27.60^{bc}	26.60^{abcd}	25.50^{abc}	24.70^{a}
P2 *10.5µl/L	43.57^{abcd}	40.42^{abc}	28.07^{bcd}	27.07^{bcde}	25.63^{abc}	24.77^{a}
P2 *3.5µl/L	50.97^{bcd}	42.03^{abc}	28.27^{bcd}	27.20^{bcde}	26.13^{abc}	24.97^{a}
P2 *Untreated	51.19^{bcd}	43.32^{abc}	28.50^{bcd}	27.80^{cde}	26.33^{abc}	25.10^{a}
P3 *17.5µl/L	59.90^{cd}	43.82^{abc}	29.67^{cd}	28.00^{cde}	26.77^{bc}	25.30^{a}
P3 *10.5µl/L	62.33^{d}	45.83^{bc}	29.70^{cd}	28.33^{cde}	27.00^{bc}	25.43^{a}
P3 *3.5µl/L	62.87^{d}	51.80^{c}	30.17^{cd}	28.80^{de}	27.00^{bc}	26.33^{a}
P3 *Untreated	63.43^{d}	52.17^{c}	30.87^{cd}	29.57^{e}	28.80^{c}	28.07^{b}
LSD (5%)	20.01	16.06	2.97	2.96	3.80	9.88
SE (+)	11.56	13.80	1.76	1.75	2.24	5.83
CV (%)	22.23	23.19	2.44	2.39	3.02	7.89

* In each column, means followed by the same letter (s) are not significantly different by Least Significant Difference (LSD) test at $p \leq 0.05$; P1= Export standard cardboard boxes with non-perforated PEP; P2= Export standard cardboard boxes with perforated PEP P3= Standalone export standard cardboard boxes (without inner PEP).

Table 30. Pearson correlation coefficient among different physicochemical parameters of banana fruits subjected to 1-MCP and packaging materials

	Firmnes	TSS	P^H	TA	TSS:TA	Starch Index	PWL	Pulp DM	Color Index	Peel ColT
Firmness	1									
TSS	-.65**	1								
P^H	.58**	-.69**	1							
TA	-.28**	.16*	-.11	1						
TSS:TA	-.56**	.95**	-.65**	-.15*	1					
Starch Index	-.58**	.71**	-.48**	.32**	.61**	1				
PWL	-.60**	.59**	-.53**	.34**	.48**	.41**	1			
PulpDM	.51**	-.49**	.59**	-.15*	-.43**	-.29**	-.44**	1		
Color Index	-.56**	.71**	-.48**	.38**	.59**	.89**	.48**	-.33**	.65**	1
PeelColT	-.71**	.61**	-.55**	.36**	.50**	.62**	.56**	-.45**	.55**	.61**

**. Correlation is significant at the 0.01 level (2-tailed);
*Correlation is significant at the 0.05 level (2-tailed).

Where:

PulpDM= Pulp diameter; PWL= Physiological weight loss; PeelCol T= Total peel color change

Note: Starch content was indirectly measured through the iodine-staining method and expressed in terms of the unstained area of the pulp (refer starch data collection procedure under Materials and Methods).

CHAPTER 6: EFFECT OF TRADITIONAL KEROSENE SMOKING AND ETHREL ON RIPENING, SHELF LIFE AND QUALITY OF CAVENDISH BANANA (Musa spp.)

Abstract

The effect of banana treatment with traditional kerosene smoking and ethrel released ethylene was investigated to determine their efficacy on ripening, shelf life and physicochemical quality attributes. Fruits at full maturity stage that are light green and three quarter full were used.The study was consisted of three factors namely ripening techniques (conventional kerosene smoking and Ethrel), exposure times(i.e. 18h, 24h and 30h),and cultivars(Williams I, Poyo and Giant Cavendish). Fruits were conventionally treated with kerosene smoke released from kerosene burners and ethylene released from 10 ml of Ethrel solution (2-chloro ethyl phosphonic acid). They were equally treated under airtight conditions over three sets of exposure times inside locally standard 3m x 2m x 3 m sized six separate commercial banana ripening chambers. Fruits were then sequentially withdrawn from the chambers on the basis of their respective exposure times and studied under ambient conditions (23 ± 1^0C and 73±1% RH). All parameters tested were invariably and progressively affected by treatment combinations over the experimental period. Significant differences ($p \leq 0.05$) in mean values were also recorded in all parameters at different stages of the ripening period. A three way significant ($p \leq 0.05$) interaction effect of the three factors was revealed on the 7th day of the ripening period on the major quality parameters, starch, TSS, and TSS/TA. Sensory quality evaluation results conducted on the 7th day of the ripening period also showed a similarly highly significant interaction effect among the treatment combinations on all quality attributes tested. Ethrel treated fruits demonstrated higher sensory quality mean score values in color (3.85), flavor (3.89), taste (3.80), aroma (3.66) and total acceptability (3.67), other than mouth- feel (3.37). Fruits treated with all treatment combinations of the kerosene smoking system equally completed their maximum ripening stage on the 7th day of the ripening period. However, at this stage, fruits were found developing some off ripening effect black scars on the peel in addition to the relatively low quality attributes recorded upon them through the sensory evaluation panel. Fruits treated with ethrel completed their ripening stage on the 7th day only at the exposure time of 30h. Those exposed to 18 h and 24 h exposure times took more time and extended their ripening stage to up to the 11th day. Thus, in terms of ripening efficiency, the kerosene smoking system can be used at the lowest exposure time of 18h under the conditions tested. The ethrel-based ripening system can similarly be used for equal ripening efficiency and better sensory quality attributes but only at the highest exposure time of 30h.

Key words: *Banana, Ripening, Shelf life, Physicochemical Quality, Kerosene Smoking, Ethrel*

6.1. Introduction

Dessert banana and plantain (*Musa sp.*) are the fourth most important staple food crops in the world after rice, wheat and maize (Salvador *et al*., 2007). They are also important sources of income for many smallholder Sub-Saharan Africa farmers (FAOSTAT, 2012).

In Ethiopia, dessert banana is the most important fruit crop, which grows in several parts of the country where the growing conditions are conducive. It is predominantly grown by smallholder farmers and is of great socioeconomic importance, especially in the south and southwestern parts of the country. In 2011, the area cultivated with banana in Ethiopia was 24,212 hectares with a total production of 235,824 tons (FAOSTAT, 2012). However, although the demand for banana is steadily increasing in Ethiopia, it is so far grown only on less than one percent of the gross cultivated area, contributing only less than 0.8% of the gross value of agricultural outputs and quite negligible in export earnings (CSA, 2009). Besides, although some studies have been sporadically reported, no significant information is so far available regarding the marketing and postharvest handling systems of banana including ripening.

The dominant commercial cultivars currently cultivated in Ethiopia are Dwarf Cavendish, Giant Cavendish, and Poyo. Cultivars like Williams I, Williams II and Grand Naine are also recently becoming into picture particularly in the Arba-Minch area where around 90% of the banana marketed in Ethiopia comes from (CFC, 2004). Others like Robusta and Butuzua are also among the recently released Cavendish banana cultivars in Ethiopia but their production is limited to certain commercial farms. The rest are less popular land races grown to a very limited extent in certain localities across the country.

Natural ripening of mature banana may result in softening with non-uniform, dull, pale yellow and unattractive color (Eduardo, 2012). In order for the fruit to attain a bright yellow peel color, a firm pulp texture, and good flavor, bananas are commercially ripened by releasing ethylene into a sealed chamber under controlled temperature and relative humidity. In doing so automated ethylene gas generators are used with calculated ethylene concentrations and exposure time. One main reason for such controlled ripening is to provide retailers and wholesalers with fruits at a stage of ripeness desired by consumers (Eduardo, 2012).

Conversely, in Ethiopia, different traditional ripening techniques are employed; which their effectiveness and effect on shelf-life and the subsequent physicochemical quality attributes are not yet studied and quantified. The most common traditional commercial banana ripening system in Ethiopia where different layers of bunches, in some cases hands, are treated involves the use of what is locally alternatively called "Chella" or "Muket" houses. Such houses, often owned by banana wholesalers, are basically airtight rooms inside which people apply kerosene smoking using kerosene burners. This traditional practice is generally known to accelerate the banana ripening process due to the presence of both acetylene (C_2H_2) and ethylene (C_2H_4) in the smoke (Sarananda, 1990). However, as stated by the same author and other previous reports, the system is often liable for lower consumer attraction, and so is being disregarded in many countries, owing to the resultant burnt scars, bruises, microbial infections, poor appearances on the peel, and contamination of the natural aroma of the fruits with the smoke. As an alternative and relatively improved ripening technique, ethylene generated from 10ml of ethrel solution (ethephon or 2-chloro ethyl phosphonic acid, $C_2H_6ClO_3P$), is also practiced in some developing countries for ripening of banana fruits often at semi-commercial levels for exposure time of 12-24 hours (ICAR, 2009).

The aim of this study was thus to compare the efficacy of the traditional commercial kerosene smoking system in Ethiopia with the ethrel released ethylene system used elsewhere in the world in terms of ripening, shelf life and physicochemical quality attributes.

6.2. Materials and Methods

6.2.1. Description of the study area

The experiment was carried out at Jimma University College of Agriculture and Veterinary Medicine (JUCAVM), under the laboratory of the Department of Postharvest Management (PHM). JUCAVM is found in Jimma town, which is 355 km southwest of Addis Ababa, geographically located at about $7^0$4'N latitude and 36^0 5' E longitude with an altitude of 1780 meters above sea level. The mean maximum and minimum temperatures were 26.8^0C and 11.4^0C respectively, and the mean maximum and minimum relative humidity were 91.40% and 39.92% respectively.

6.2.2. *Experimental design and treatments*

The experiment was laid out in a Randomized Complete Block Design (RCBD) with a 2*3*3 factorial arrangement in three replications. The factors consisted of (1) Factor A: Ripening Techniques in two levels (i.e. kerosene smoking with kerosene burners (K) and ethrel generated ethylene (E); (2) Factor B: Exposure-Time in three levels (i.e. 18 hours, 24 hours=local standard, and 30 hours); and (3) Factor C: Cultivars in three levels (i.e. Williams I=C1, Poyo=C2 and Giant Cavendish=C3). In total, there were 18 treatment combinations and 54 experimental units.

6.2.3. *Experimental procedures*

6.2.3.1. *Harvesting and transportation of banana bunches*

Banana bunches of three selected Cavendish cultivars; Williams I (C1), Poyo (C2) and Giant Cavendish (C3) were obtained from Tepi Agricultural Research Center, which is located about 274 km southwest of Jimma town or 629 km southwest of Addis Ababa, Ethiopia. Fifteen matured bunches of light-green color and about three quarter full fingers, were selected from the "Banana Variety Maintenance Trial" field. They were selected from prior selected and tagged plants that were healthy, robust and relatively uniform. Fruit bunches were carefully harvested late in the afternoon (4:00 to 5:00 p.m.) and carried on a shoulder pad of the harvesters and kept under natural tree shade for three hours in order to pre-cool the bunches, remove the field heat and slow down metabolism. Initial temperature of each bunch was recorded using a Thermo-Hygrometer (model: PWT-101, Mauritius). The bunches were then night transported to the traditional commercial banana ripening houses in Jimma town by ISUZU truck cushioned with banana leaves from all sides except from the top.

6.2.3.2. *Preparation of banana hands for ripening treatment*

Upon arrival at the commercial ripening houses in Jimma town, bunches were carefully unloaded and stabilized for two hours inside a ventilated shade house. Once again, the temperature of each bunch was recorded immediately after unloading using the same Thermo-Hygrometer. Bunches were then carefully de-handed in a cluster of five fingers per crown with a very sharp curved knife in order to remove most of the rachis. De-handing was performed by hanging bunches down wards from a hook and the process proceeded from the apex to the basal end in order to avoid damages to individual fingers.

In order to maintain the uniformity of the experimental materials, only uniform (in terms of overall appearance, size and stage of maturity), clean and undamaged hands were de-handed from the central part of each bunch by avoiding those in the basal and apical rows. Care was also taken to prevent the hands from bumping against each other during de-handing and washing. Immediately after de-handing, but before treatment, hands were carefully placed into the washing tank or tub and washed using 2% normal “Barakina” (Sodium hypochlorite, NaClO) for 3 minutes in clean tap water. This was done for surface disinfection and removal of the latex and any other dirt. The hands were inspected one by one for any remaining dirt, which was gently removed using wet sponge. In order to completely remove the “Barakina” from the hands, hands were sequentially transferred into the second and third tanks and rinsed with clean tap water. In the end, the hands were drained off (air dried) on a wire-meshed platform with newspaper bedding. The crowns of the hands were also brushed with Aluminum Sulphate to avoid latent infection. This process of washing and draining off the hands was carried out under shade house and took around two hours.

6.2.3.3. Preparation and treatment of banana cultivars using kerosene smoking

Three traditional commercial banana ripening chambers, locally called “Chella” or “Muket” houses, with an area of 3m*2m*3m=18m^{3}were used from the commercial banana ripeners in Jimma town. The washed and air-dried banana hands of the three banana cultivars were put separately inside perforated plastic boxes and placed on top of weaved wooden shelves. The hands were then conventionally treated with smoke generated from two kerosene burners per room, each filled with 2 liters of kerosene, for the respective durations stated above (i.e. 18, 24 and 30 hours). The ripening treatment process was started simultaneously at 12:00 a.m. in all ripening rooms. As conventionally practiced by the “Chella” house operators in Jimma town and elsewhere in Ethiopia, the ripening rooms were closed and air tightly sealed up until the end of their respective exposure times. The pulp temperature and relative humidity of the respective ripening rooms were recorded at the beginning and end of the ripening process.

6.2.3.4. Preparation and treatment of banana cultivars with ethrel

Ethylene, in the presence of alkaline medium such as sodium hydroxide (NaOH), evolves from Ethrel to treat climacteric fruits such as banana and promote ripening (Mohammed *et al*., 2003; ICAR, 2009). Using the same procedure, a 10 ml of Ethrel solution ($C_2H_6ClO_3P$) and 2 gm of NaOH pellets were mixed in 5 liters of water in a wide mouthed plastic buckets inside the respective ripening chambers of the three exposure times (i.e. 18, 24 and 30 hours). This was presumed to release 100-150 µL L^{-1}ethylene, which is the common concentration level used for banana ripening at destination markets (Mohammed *et al*., 2003; ICAR, 2009). This, in place of the smoke released through kerosene burners, was used to treat fruits of the three banana cultivars through the liberated ethylene inside the respective air tight ripening chambers for the specified exposure times. A small portable electric operated fan (Model: REE-NOVA FH-04: 220-240V/50~60Hz, China) was placed near the buckets in each of the respective ethrel treatment chambers to facilitate the release and uniform circulation of the ethylene gas from the solution. The chambers were then sealed air-tight immediately after recording the prevailing temperature and relative humidity.

6.2.3.5. Termination of the ripening process and subsequent handling of treated fruits for analysis

At the end of the respective treatment periods, the temperature and relative humidity of the rooms were recorded and the treated fruits were withdrawn from the ripening rooms in order to terminate the process and keep them under ambient conditions inside the laboratory of the Department of Postharvest Management at JUCAVM. Then, fruits were assigned into meshed plastic trays (35 fingers per tray), which were randomly laid out as per the design of the experiment across the laboratory benches. Finally, samples of fruits were periodically taken for physicochemical quality analysis up until the end of their marketable life. In addition to the physicochemical measurements taken immediately after harvest (i.e. before the ripening treatment), which is considered as a Day Zero measurement, random samples of 3-5 fruits were used for subsequent analysis at three days interval. The temperature and relative humidity of the display room were recorded three times a day (i.e. morning, mid-day and late afternoon) throughout the experimental period. Ripening fruits were also inspected and records were taken every day for problems like disease incidence and physiological deterioration.

6.2.4. Data collected

Data collection was started right after the arrangement of the hands in the laboratory to the respective treatments and before the application of the ripening treatments. In addition to observations taken on Day one after treatment, data collection was then continued at three days interval up until the fruits became unmarketable. Data were collected for the following physical and chemical properties of the experimental fruits.

6.2.4.1. Physical parameters:

Physiological weight loss of fruits (PWL %)

Physiological weight loss of fruits was recorded through periodical weighing of five sample fingers from each experimental unit throughout the experimental period using a precision scale (model: LS200 Sartorius GMBH Gottingen, Germany). Physiological Weight Loss of fruits in the respective treatments was calculated and expressed as a percentage of the initial weight using the following equation.

$$Weight\ loss(\%) = \frac{Initial\ weight(g) - Final\ weight(g)}{Initial\ weight(g)} \times 100 \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{Equation. 1}$$

Fruit firmness (N)

Fruit firmness was measured using a Texture Analyzer (Model: TA-XT Plus, UK) and calculated by employing the method used by Fan *et al*. (1999). Two whole unpeeled fingers were used periodically from each treatment to measure the penetration force required to penetrate the fingers by the stainless plunger and the force was automatically recorded and expressed in Newton (N). The mean value of measurements taken from two fingers of the respective treatments was recorded as the mean firmness.

Fruit peel color

Peel color was measured using the Tri-Stimulus Colorimeter (AccuProbe HH06, USA), which was regularly calibrated before measurement with a Minolta standard white tile to L=83.14, a=-3.67 and b=10.79. Non-destructive measurements were taken periodically starting from Day0 (Day Zero) at three days interval to the end of the experimental period and values were recorded as *a, b* and *L*. Multiple measurements were taken from two sample fruits on two opposite sides and mid- point to the two ends of each fruit. Color values for each sample were calculated as the means of the four measurements taken.Total colour change of samples was determined using the CIE (Commission Internationale de L'Eclairage) 1976 *L*a*b color scale* system, where *L**scale measures lightness ('light vs. dark') and varies from 100 for perfect white to zero for perfect black (i.e.0-50 indicates dark while 51-100 indicates light); *a** measures redness ('red vs. green') (positive when red and green when negative); and *b** measures yellowness ('yellow vs. blue') yellow when positive and blue when negative).The total color change (ΔE) was calculated by employing the following formula (AOAC,1984).

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$$\Delta E = \sqrt{(L^*_i - L_f)^2 + (a^*_i - a_f)^2 + (b^*_i - b_f)^2} \quad \text{-----Equation 2}$$

Where:
i= initial, and f= final

6.2.4.2. Chemical parameters

Pulp starch content

Starch staining was carried out by a 3-5 minutes dipping of a cross-sectional cut of the unpeeled sample fruits in a starch-iodine staining solution with10g potassium iodide (KI) and 2.5g iodine (I_2) in 250 ml distilled water. It was carried out as per the rapid starch staining method and chart developed by Sylvia *et al*. (1993).The stained part of the sample fruit slices were then turned up and put in an upright position for about 2 minutes in order to allow the excess solution to be drained off. A transparent plastic sheet was then traced on the patterns of the stained areas and estimated in relation to the whole surface area of the cut dipped portion of the fruits. The sample fruits were then rated based on the chart developed previously into 10 distinguishable stages with rating numbers ranging from 1 to 10 based on the percentage of unstained area, i.e. 1 means <5% unstained area, 2 (5%), 3 (10%), 4 (15%), 5 (25%), 6 (35%), 7 (45%), 8 (55%), 9 (65%) and 10 (>65%). The degree of ripening as well as the corresponding starch contents of the sample fruits was determined accordingly. A trend of increase in the rating number, from 1 to 10, was expressed as a characteristic pattern of starch loss during ripening.

Total soluble solids-TSS (°Brix)

Sample fruits were peeled and blended using a juice blender and TSS of the pulp juice was measured by the refractive index, expressed as °Brix, by a portable hand Refractometer (Model: SN-003007). The macerated samples were homogenized by adding about 40 ml of distilled water and filtered with cheese cloth. One to two drops of the filtrate was then placed on to the glass prism of the refractometer for reading within the scale. The glass prism was rinsed with distilled water and cleaned with cheese cloth in between the measurement of each of the samples drawn from the experimental units.

Titratable acidity (TA)

Titratable acidity was measured for samples of each experimental unit by titrating the pulp filtrates with 0.1N NaOH solution with 2 to 5 drops of phenolphthalein up until the indicator light pink color appeared. The volume of NaOH used up until the indicator reach the end point color was then recorded and TA was expressed as percentage of malic acid (Hewage, 1996) in the pulp weight of the titrate as calculated using the following formula.

Titratable Acidity (%) = $\frac{V1*N*E}{V2}\ x\ 100$ ……………………………………Equation 3

Where:

N = Normality of NaOH

V_1 = Volume of NaOH used

E = Equivalent weight of Acid

V_2 = Volume of sample taken for estimation

TSS:TA ratio

The ratio between total soluble solids and titratable acidity was determined by dividing the values for TSS to the values of TA of the same sample fruit.

Pulp pH

The pH of the sample fruit juice was measured using a bench top digital pH meter (model: CP-505, Poland). The pH meter was periodically calibrated with buffer at pH 4.0 and 7.0 before taking the measurements. pH was expressed as the equilibrium measure of hydrogen ion concentration in the sample fruit juice.

6.2.4.3. Sensory quality

The organoleptic or sensory quality of sample fruits from each treatment was determined using 5-point hedonic scale (where 1= dislike, 2= slightly, 3=neither dislike nor like, 4= slightly like, and 5= like; Mustaza, 2008). A panel of 40 pre-oriented under and post graduate students from the departments of Horticulture and Postharvest Management were considered for the evaluation. The evaluation was carried out on the 7th day of the ripening period when most of the sample fruits attained the 6thcolor chart scale according to methods reported by Larmond (1987).The evaluation was made for such quality attributes like pulp color, flavor, taste, aroma, mouth-feel, and overall acceptability. The sample fruits were peeled, hand sliced into smaller equal pieces and served in a random order across the laboratory benches of the Department of Postharvest Management in 3-digit coded flat glass trays. Distilled water was provided for the evaluators to cleanse their palates between each test sample. The panel test was carried out from 10:00 a.m. to 11:30 a.m. in the morning. The evaluation results were statistically analyzed to determine whether or not there were statistically significant differences in consumer preferences.

6.2.5. Statistical analysis

The experimental data were analyzed through the Analysis of Variance (ANOVA) by employing SAS software version 9.2. The Least Significant Differences (LSD %) test was used to determine the level of significance at 5% ($P < 0.05$) and for mean separation and comparison of their differences among the treatment means. Data on main factor effects and their corresponding interaction effects are presented as results of the experiment only when they showed statistically significant differences.

6.3. Results and Discussion

6.3.1. Physical characteristics:

Physiological weight loss (PWL %)

Physiological weight loss increased consistently as the ripening period prolonged in all treatments (Figure 8).

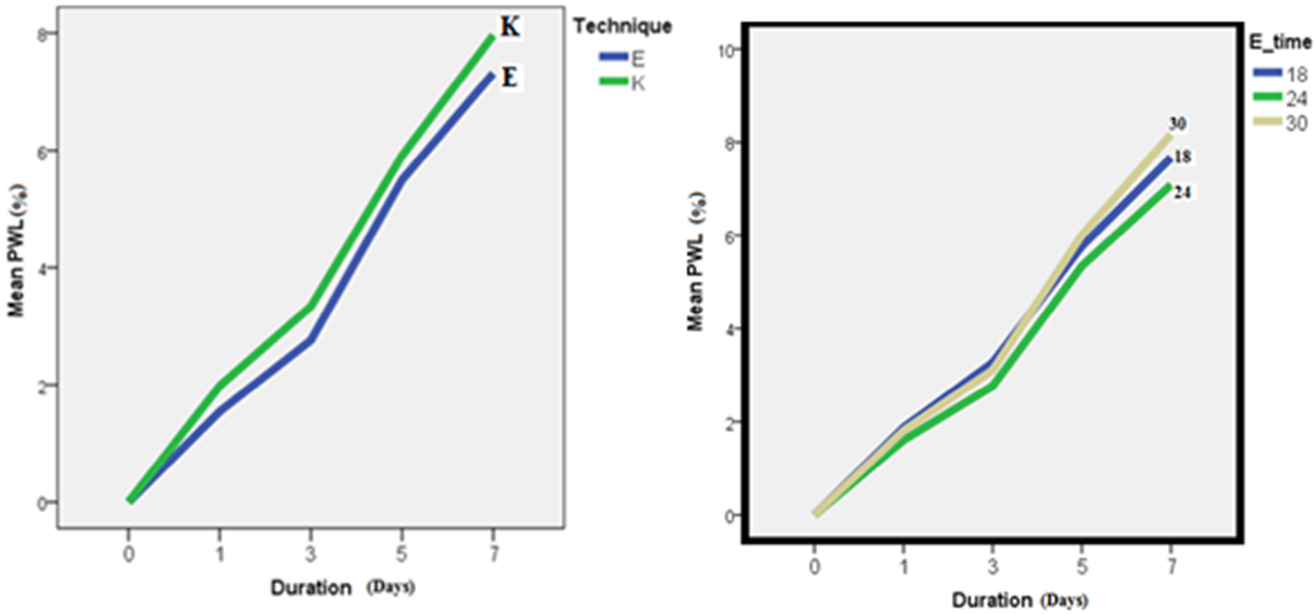

Figure 8. Trend of changes in PWL (%) banana fruits in response to ripening techniques and exposure periods

The increase in weight loss with the application of the kerosene smoking and ethrel-based ripening systems was probably due to the upsurge in respiration rate of the sample fruits over the ripening period. Dhall *et al.* (2013) also reported a similar increase in PWL (2.23 to 8.60%) during tomato ripening with ethrel and ethylene which was attributed to the increased rate of respiration as well as transpiration from the peel surface with the advance of ripening. The two-way interaction effect of ripening techniques and cultivars showed a significance difference ($p<0.05$) among cultivars treated with the kerosene smoking and ethrel-based ripening system on the 7th day of the ripening period (Table 31). However, while all cultivars recorded the highest weight loss (7.68%-8.35%) on the 7th ripening day with the kerosene smoking-based system, only Giant Cavendish recorded a similar loss under both ripening systems on the same day. All cultivars showed similar levels of weight loss with the ethrel-based ripening system after the 9thday of ripening (Table 32).Thus, the kerosene smoking-based system significantly increased the weight loss invariably much earlier than the ethrel-based system signified that it was more efficient in the acceleration of the ripening process than the later.

Table 31. Interaction effect of ripening techniques and cultivars on PWL (%) on Day 7

Cultivar	Kerosene smoking	Ethrel
Williams I	8.10^{ab}	7.17^{bc}
Poyo	8.12^{ab}	6.43^{c}
Giant Cavendish	7.68^{ab}	8.35^{a}
SE (±)	1.2	
CV (%)	15.73	
LSD (5%)	1.09	

* In each column, means followed by the same letter (s) are not significantly different ($p \leq 0.05$)

Table 32. Effect of cultivars on PWL (%) of fruits treated with ethrel alone on Day 9

Cultivars	%
Williams I	8.95^{ab}
Poyo	7.84^{b}
Giant Cavendish	10.3^{6a}
SE (±)	1.61
CV (%)	17.8
LSD (5%)	1.61

* In each column, means followed by the same letter (s) are not significantly different ($p \leq 0.05$)

Note: Fruits treated with the kerosene smoking completed their marketable shelf life and discarded on the 7th day of the ripening period. Thus mean values shown for the 9th are only for fruits treated with ethrel alone

Firmness (N)

The data on banana fruit firmness revealed a decreasing trend during the ripening period for all treatments (Figure 9).

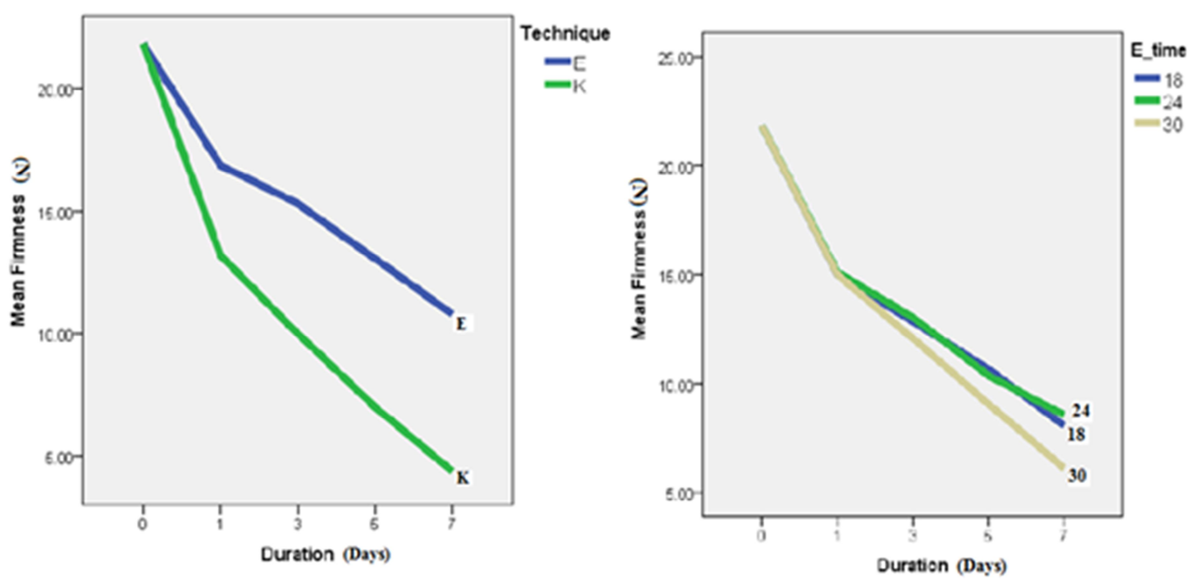

Figure 9. Trend of changes in firmness (N) banana fruits in response to ripening techniques and exposure periods

Significant differences ($p \leq 0.05$) among mean values of firmness were recorded at different stages of the ripening period. The firmness of fruits averagely decreased significantly from 21.87N on Day0 to 4.36N on the 7^{th} day of the ripening period. While fruits treated with the kerosene smoking system attained the above stated minimum firmness level on the 7^{th}day of ripening with all exposure times (Tables 33 and 34), those treated with ethrel attained a similar level of firmness only at the 11^{th} day of the ripening period with the exposure time of 30 hours (Table 35). With the exposure times of 18 h and 24 h, varieties treated with ethrel showed differences with only Williams I and Poyo attaining the stated level of firmness at the 11^{th} day of the ripening period. Venkata *et al*. (2012) also reported a similar finding on Grande Naine banana fruits, treated with smoking and ethrel, declined in firmness to 4.83 on the 8^{th} day of the ripening period.

The decline in firmness was so drastic between the initial two days and thereafter decreased gradually throughout the ripening period. This consistent softening or decline in firmness corresponds to an inter conversion of insoluble pectic substances into soluble pectin (i.e. by cellular disintegration leading to membrane permeability) over the ripening period (Venkata *et al*., 2012). Tapre *et al*. (2012) also reported that the softening of banana fruits during ripening treatment is associated with the conversion of starch to sugar, the breakdown of pectin substances and the movement of water from the rind of the banana to pulp during ripening. As stated by Sandipkumar *et al*. (2015), changes in biochemical and other properties such as peel thickness, TSS and moisture or pulp dry matter content are the main cause of alteration in mechanical properties such as firmness in banana. The result in the present study is further consolidated by the fact that the correlations between firmness and TSS as well as firmness and pulp dry matter content were found to be strongly negative (R=-0. 86) and moderately positive (R=0.58), respectively (Table 52).

Table 33. Interaction effect of ripening techniques and exposure times on firmness (N) of banana fruits on Day 7

Duration (hrs)	Kerosene smoking	Ethrel
18	4.59[c]	12.53[a]
24	4.30[c]	11.93[a]
30	4.20[c]	7.90b
SE (+)	1.48	
CV (%)	19.48	
LSD (5%)	1.41	

* In each column, means followed by the same letter (s) are not significantly different ($p \leq 0.05$)

Table 34. Interaction effect of ripening techniques and cultivars on firmness (N) of banana fruits on Day 7

Cultivar	Kerosene smoking	Ethrel
Williams I	4.49[c]	8.90[b]
Poyo	4.31[c]	10.01[b]
Giant Cavendish	4.29[c]	13.46[a]
SE (+)	1.48	
CV (%)	19.48	
LSD (5%)	1.41	

* In each column, means followed by the same letter (s) are not significantly different ($p \leq 0.05$)

Table 35. Interaction effect of exposures times and cultivars on firmness (N) of banana fruits treated with ethrel alone on Day 9 and Day 11

Cultivar	Day 9			Day 11		
	18 hrs	24 hrs	30 hrs	18 hrs	24 hrs	30 hrs
Williams I	6.87[cbd]	6.07[cd]	5.97[cd]	4.67[b]	4.00[b]	3.87[b]
Poyo	9.83[b]	8.77[cb]	6.20[cd]	5.83[b]	5.30[b]	4.77[b]
GiantCavendish	15.43[a]	15.60[a]	5.67[d]	13.73[a]	13.23[a]	4.30[b]
SE (+)	1.72			1.14		
CV (%)	19.2			17.21		
LSD (5%)	2.97			1.98		

* In each column, means followed by the same letter (s) are not significantly different ($p \leq 0.05$)

Note: Fruits treated with the kerosene smoking completed their marketable shelf life and discarded on the 7[th] day of the ripening period. Thus mean values shown for the 9th & 11th are only for fruits treated with ethrel alone.

Peel color

Significant differences ($p \leq 0.05$) in mean values of total peel color change were found at different stages of the ripening period. The obvious manifestations of banana color change during ripening such as the disappearance of the green peel color and the corresponding yellowing were clearly observed in the present experiment irrespective of variations in treatments (Figure 10).

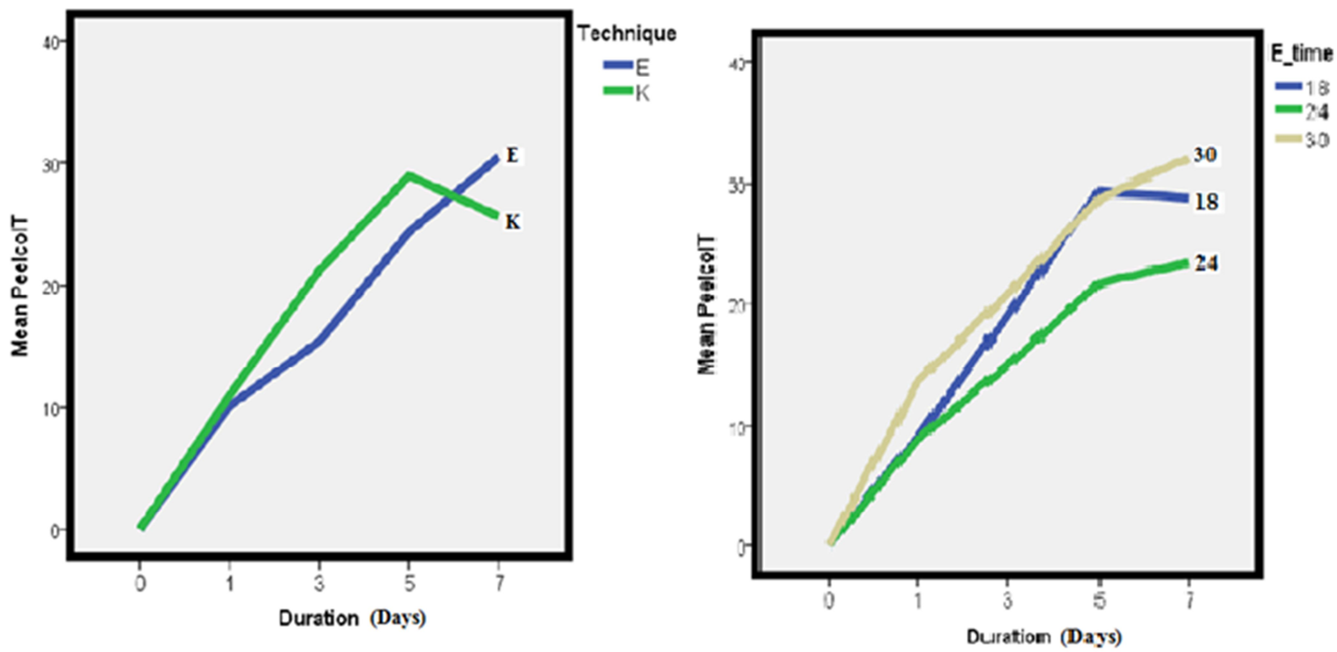

Figure 10. Trend of total peel color change of banana fruits in response to ripening techniques and exposure periods

The results were in agreement with the reports of Salvador *et al*. (2007) and Tourky *et al*. (2014) in that the progressive loss of the green color in the peel was due to the continuing degradation of the chlorophyll structure during ripening.

The highest total peel color change was recorded on the 7th day of the ripening period for fruits treated with kerosene smoking across all exposure times (Table 36 and 37). On the other hand, fruits treated with ethrel extended the trend till the 9th day and then declined on the 11th day (Table 38). This could be attributed to the much accelerated ripening effect of the kerosene smoking ripening system, which triggered all cultivars to complete their ripening period much earlier than the ethrel-based system. Similar results were also found by Ding *et al*. (2006) who reported that the color change of the peel implied the ripeness of Berangan banana and William Cavendish in that as the fruits ripen, they progressively developed a bright yellow color as chlorophyll gets degraded and carotenoids become visible. Thereafter the peel color declined as brown spots (senescence) appeared on the skin and the fruits became overripe.

On the other hand, it was observed that fruits treated with the ethrel-based ripening system developed uniform yellow peel color; while those treated with kerosene smoking exhibited deep yellow color with black spots on the peel surface leading to over-softening of the fruits at the end of the ripening period. A similar result was earlier reported by Sarananda (1990) that although the traditional banana ripening practice by smoking and subsequently storing at room temperature accelerates the ripening process, the resultant burnt scars, bruises, microbial infections and poor appearance of smoked ripe fruits lower consumer attraction.

Table 36. Interaction effect of ripening techniques and cultivars on total color change of banana fruits on Day 7

Cultivar	Kerosene smoking	Ethrel
Williams I	23.07^{c}	33.39^{a}
Poyo	26.24^{bc}	31.41^{ab}
Giant Cavendish	27.66^{abc}	26.63^{ab}
SE (+)	6.57	
CV (%)	23.40	
LSD (5%)	6.29	

* In each column, means followed by the same letter (s) are not significantly different ($p \leq 0.05$)

Table 37. Effect of exposure times on total color change of banana fruits on Day 7 of storage

Duration (hrs)	Color Change
18	23.37a
24	28.85^{a}
30	31.98^{a}
SE (+)	6.57
CV (%)	23.4
LSD (5%)	4.45

* In each column, means followed by the same letter (s) are not significantly different ($p \leq 0.05$)

Table 38. Effect of exposure times on total color change of banana fruits treated with ethrel alone Day 9 and Day 11

Duration (hrs)	Day 9	Day 11
18	29.61^{b}	28.48^{b}
24	34.88^{ab}	32.88^{b}
30	40.03^{a}	40.56^{a}
SE (+)	7.16	6.94
CV (%)	20.56	20.42
LSD (5%)	7.16	6.93

* In each column, means followed by the same letter (s) are not significantly different ($p \leq 0.05$)

Note: Fruits treated with the kerosene smoking completed their marketable shelf life and discarded on the 7th day of the ripening period. Thus mean values shown for the 9th & 11th are only for fruits treated with ethrel alone

6.3.2. Chemical characteristics

Starch

The starch stained a blue-black color, while areas that have lost starch remained white. Significant differences ($p \leq 0.05$) were found in starch un-staining at different stages of the ripening period (Figure 11). The proportion of unstained area increased faster from 1(<5% unstained) at the beginning to 10 (>65% unstained) on day 7 of the ripening period with the kerosene smoking system for all three exposure times and cultivars (Table 39). Under the ethrel-based ripening system, cultivars showed a similar extent of starch unstaining on day 7 of the ripening period only at the exposure time of 30 hours (Table 39).

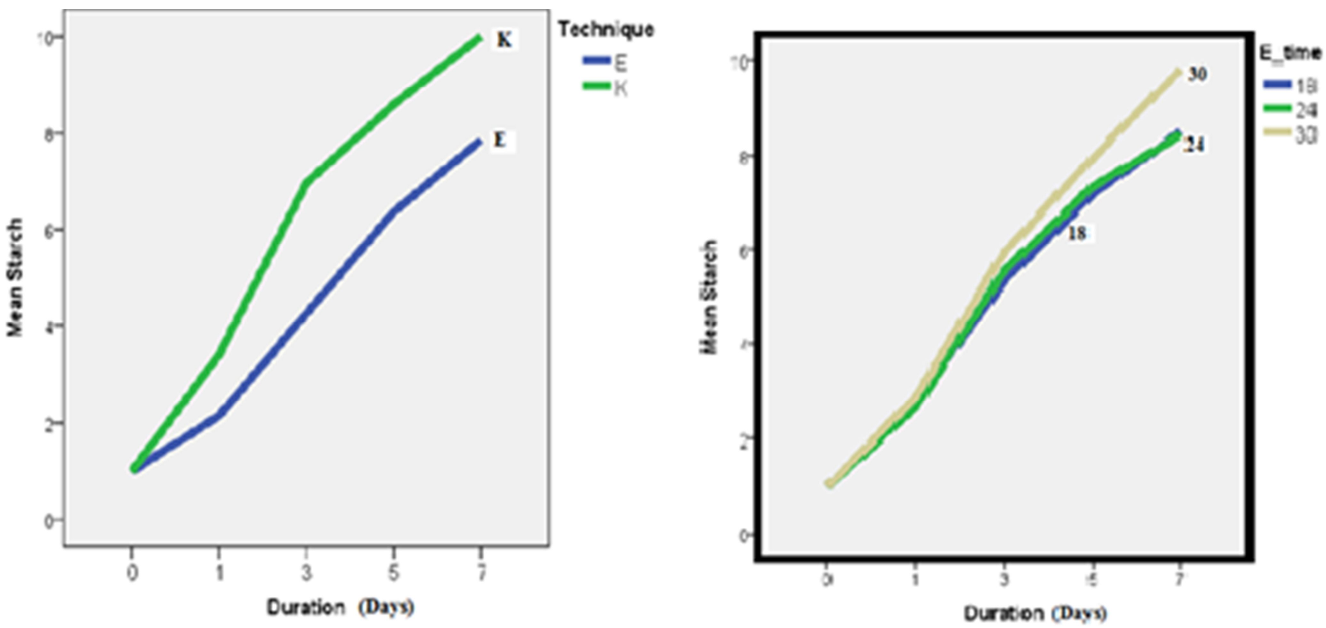

Figure 11. Trend of changes in starch unstaining index of banana fruits in response to ripening techniques and exposure periods

With the 18 h and 24 h exposure times, cultivars exhibited similar level of starch un staining only on the 11th day of the ripening period (Table 40). This significant disappearance of starch on day 7 of the ripening period of the cultivars showed a highly significant correlation with peel color (R=0.82), TSS (R=0.96), and p^H (R=-0.80) (Table 52). The results are in agreement with previous findings by Tourky *et al* (2014) in that starch hydrolysis is the most important postharvest biochemical change which occurs during the postharvest ripening of banana and causes the accumulation of sugar that are responsible for the increase in pulp TSS content and sweetening of the fruit.

Table 39. Interaction effect of ripening techniques, exposure times and cultivars on pulp starch unstaining index of banana fruits on day 7

Cultivar	Kerosene smoking			Ethrel		
	18 hrs	24 hrs	30 hrs	18 hrs	24 hrs	30 hrs
Williams I	10.00[a]	10.00[a]	10.00[a]	7.67[d]	8.00[c]	10.00[a]
Poyo	10.00[a]	10.00[a]	10.00[a]	7.00[e]	7.00[e]	10.00[a]
Giant Cavendish	10.00[a]	10.00[a]	10.00[a]	6.00[f]	6.00[f]	9.00[b]
SE (±)	0.14	CV (%)	1.52	LSD (5%)	0.23	

*In each column, means followed by the same letter (s) are not significantly different at ($p \leq 0.05$)

Table 40. Interaction effect of exposure times and cultivars on pulp starch unstaining index of banana fruits treated with ethrel alone on Day 9 and Day 11

Cultivar	Day 9			Day 11		
	18 hrs	24 hrs	30 hrs	18 hrs	24 hrs	30 hrs
Williams I	9.00[b]	9.00[b]	10.00[a]	10.00[a]	10.00[a]	10.00[a]
Poyo	8.00[c]	8.00[c]	10.00[a]	9.00[b]	9.00[b]	10.00[a]
Gaint Cavendish	7.00[d]	7.00[d]	10.00[a]	8.00[c]	8.00[c]	10.00[a]
SE(±)	0.37			0.26		
CV (%)	4.85			3.19		
LSD (5%)	0.43			0.42		

*In each column, means followed by the same letter (s) are not significantly different at ($p \leq 0.05$)

Note: Fruits treated with the kerosene smoking-based ripening system completed their marketable shelf life and discarded on the 7th day of the ripening period. Thus mean values shown for days 9 & 11 are only for fruits treated with ethrel)

TSS (^{0}Brix)

A significant difference ($p \leq 0.05$) was generally observed in respect of the Total Soluble Solids (TSS) of banana fruits among the treatments at different stages of the ripening period. TSS content increased consistently throughout the ripening period irrespective of treatments (Figure 12).

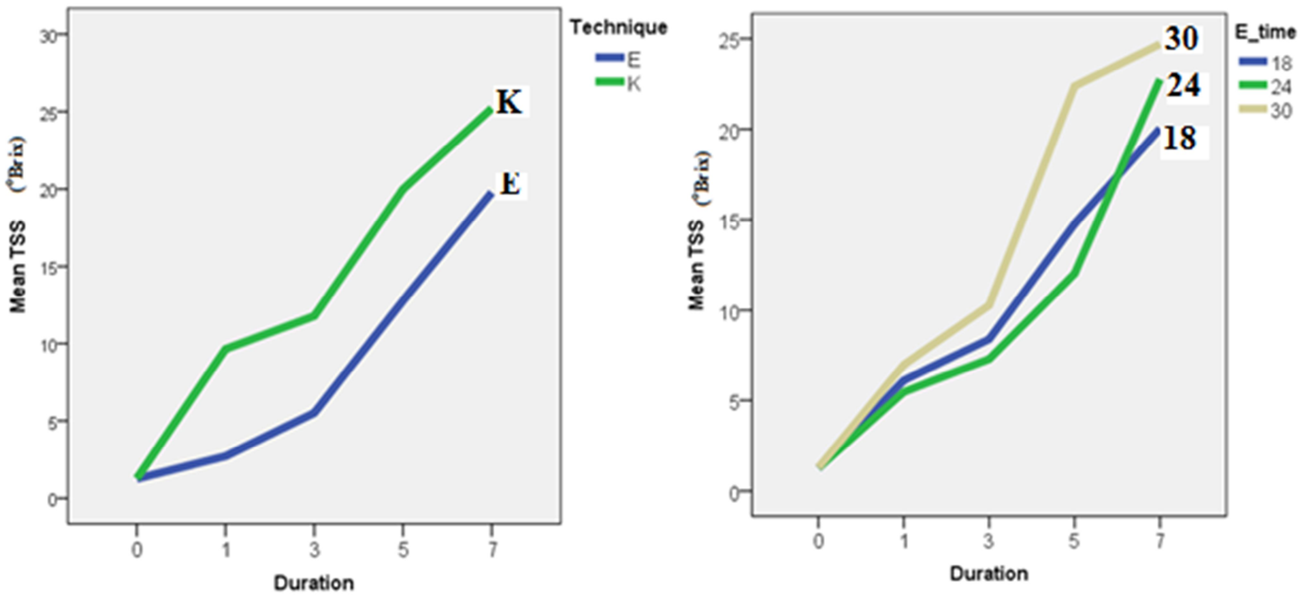

Figure 12. Trend of changes in TSS (^{o}Brix) of banana fruits in response to ripening techniques and exposure periods

Results also indicate a progressive increase in TSS and decrease in starch content with the maximum TSS (25.21 ^{O}Brix) attained at the end or 7^{th}day of the ripening period under the kerosene smoking system followed by the 9^{th} and 11^{th} day under the ethrel-based system (Tables 41and 42). These results are almost in consistency with results (23.07 ^{0}Brix) obtained by Tapre *et al*. (2012) at stage 7 of the ripening period of the banana fruits. Sandipkumar *et al*. (2015) also reported an increase in TSS from 3 ^{O}Brix to 22.24 ^{O}Brix during nine days of banana storage. In addition, Kulkarni *et al*. (2004) reported an increase in TSS and sugars in mango fruits treated with ethrel with progress in storage time. The increase in TSS during ripening may result from an increase in concentration of organic solutes as a consequence of water loss and hydrolysis of starch into soluble sugars such as sucrose, glucose and fructose (Tapre *et al*., 2012). Tourky *et al*. (2014) reported that banana and some other fruits contain many water soluble compounds (sugars, acids, vitamin C, amino acids and some pectin) that form the TSS. Total soluble solids, having sugar as their main component are known to be important postharvest quality attributes of the banana fruits that serve as the most useful index of ripeness.

Table 41. Interaction effect of ripening techniques, exposure times and cultivars on TSS (^{0}Brix) of banana fruits on day 7

Cultivar	Kerosene smoking			Ethrel		
	18 hrs	24 hrs	30 hrs	18 hrs	24 hrs	30 hrs
Williams I	25.13^{a}	25.33^{a}	25.40^{a}	19.20^{c}	20.44^{c}	23.67^{ab}
Poyo	24.53^{a}	24.77^{a}	26.00^{a}	19.00^{c}	21.27^{bc}	23.78^{ab}
Giant Cavendish	25.07^{a}	25.13^{a}	25.51^{a}	7.05^{d}	19.40^{c}	24.23^{ab}
SE (±)	1.84	CV (%)	8.2	LSD (5%)	3.06	

*In each column, means followed by the same letter (s) are not significantly different at ($p \leq 0.05$)

Table 42. Interaction effect of exposure times and cultivars on TSS (^{0}Brix) of banana fruits treated with ethrel alone on Day 9 and Day 11

Cultivar	Day 9			Day 11		
	18 hrs	24 hrs	30 hrs	18 hrs	24 hrs	30 hrs
Williams I	23.13^{ab}	23.41^{ab}	25.20^{a}	23.58^{ab}	24.b^{a}	25.87^{a}
Poyo	21.60^{a}	23.58^{ab}	24.07^{ab}	23.09^{b}	25.00^{ab}	25.87^{a}
G. Cavendish	11.74^{c}	23.73^{ab}	25.13^{a}	19.40^{c}	25.57^{ab}	25.87^{a}
SE(±)	1.73			1.44		
CV (%)	7.72			5.93		
LSD (5%)	2.99			2.5		

*In each column, means followed by the same letter (s) are not significantly different at ($p \leq 0.05$)

Note: Fruits treated with the kerosene smoking-based ripening system completed their marketable shelf life and discarded on the 7th day of the ripening period. Thus mean values shown for days 9 & 11 are only for fruits treated with ethrel)

Titratable Acidity (TA %)

Although the percentage values were recorded in the narrow range, a progressive increase in TA was found with advances in the ripening period in all the treatments (Figure 13).

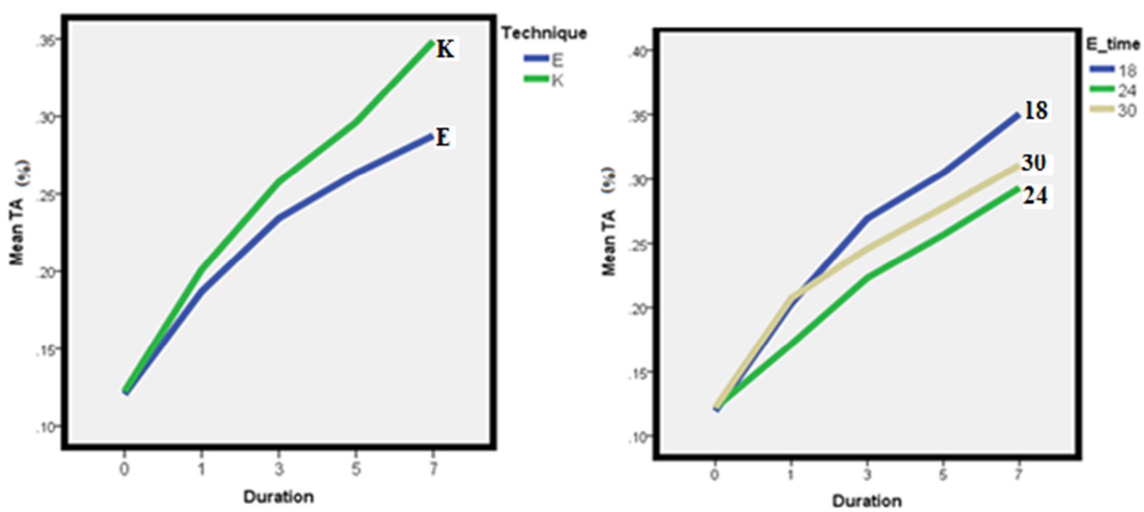

Figure 13. Trend of changes in TA (%) of banana fruits in response to ripening techniques and exposure periods

The highest percentage of TA (0.34-0.36%) was recorded on the 7th day of the ripening period similarly under the kerosene smoking system equally with all the cultivars and exposure times. Although a slight decline in TA (0.28%) was observed with the kerosene smoking treatment after the 7th day of the ripening period, the fruits were by then became unmarketable and discarded (Table 43).Fruits treated with the ethrel-based system attained similar level of TA percentage at the 7th day of the ripening period only at the exposure time of 30 hours (Table 43). There was also a two way interaction effect of exposure times and cultivars on the 9th day of the ripening period where fruits attained similar level of titratable acidity (0.34-0.35%) at 30 hours of exposure time (Table 44). Those treated with the exposure times of 18 h and 24 h extended the stage to the 11th day of ripening (Table 45). Although results were not statistically significant, similar results were reported by Tapre *et al*. (2012) with values ranging narrowly from 0.3 to 0.45% among treatments at the end of the banana ripening period. The result is as well concurring with the studies made by Siriboon *et al*. (2004) and Zeweter (2008) who reported that TA increased to its peak as ripening progressed, which coincided with the accumulation of ethylene and ripening, and then started declining afterwards. Thus, as stated by Dadzie *et al* (1997), the increase in TA over the ripening period could also be regarded as a useful index of banana fruit.

Table 43. Interaction effect of ripening techniques and exposure times on titratable acidity (%) of banana fruits on Day 7

Duration (hrs)	Kesone smoking	Ethrel
18	0.34^{a}	0.24^{b}
24	0.35^{a}	0.27^{b}
30	0.36^{a}	0.34^{a}
SE (±)	0.03	
CV (%)	10.14	
LSD (5%)	0.03	

*In each column, means followed by the same letter (s) are not significantly different at ($p \leq 0.05$)

Table 44. Interaction effect of exposure times and cultivars on titratable acidity (%) of banana fruits treated with ethrel alone on Day 9

Cultivar	Durations		
	18 hrs	24 hrs	30 hrs
Williams I	0.28[e]	0.30[de]	0.34[abc]
Poyo	0.30[de]	0.33[cde]	0.38[a]
Gaint Cavendish	0.22[f]	0.30[cde]	0.35[ab]
SE (±)	0.02		
CV (%)	7.75		
LSD (5%)	0.04		

*In each column, means followed by the same letter (s) are not significantly different ($p \leq 0.05$)

Note: Fruits treated with the kerosene smoking-based ripening system completed their marketable shelf life and discarded on the 7th day of the ripening period. Thus mean values shown for on the 9th day are only for fruits treated with ethrel

Table 45. Effect of of exposure times on titratable acidity (%) of banana fruits treated with ethrel alone on Day 11

Duration (hrs)	TA
18	0.33[b]
24	0.36[ab]
30	0.39[a]
SE (±)	0.04
CV (%)	10.91
LSD 5%)	0.04

*In each column, means followed by the same letter (s) are not significantly different at ($p \leq 0.05$)

Note: Fruits treated with the kerosene smoking-based ripening system completed their marketable shelf life and discarded on the 7th day of the ripening period. Thus mean values shown on the 11th are only for fruits treated with ethrel

TSS:TA ratio

The TSS:TA ratio, which is also taken as a ripening index (RI), generally increased as the ripening period progressed in all treatments (Figure 14).

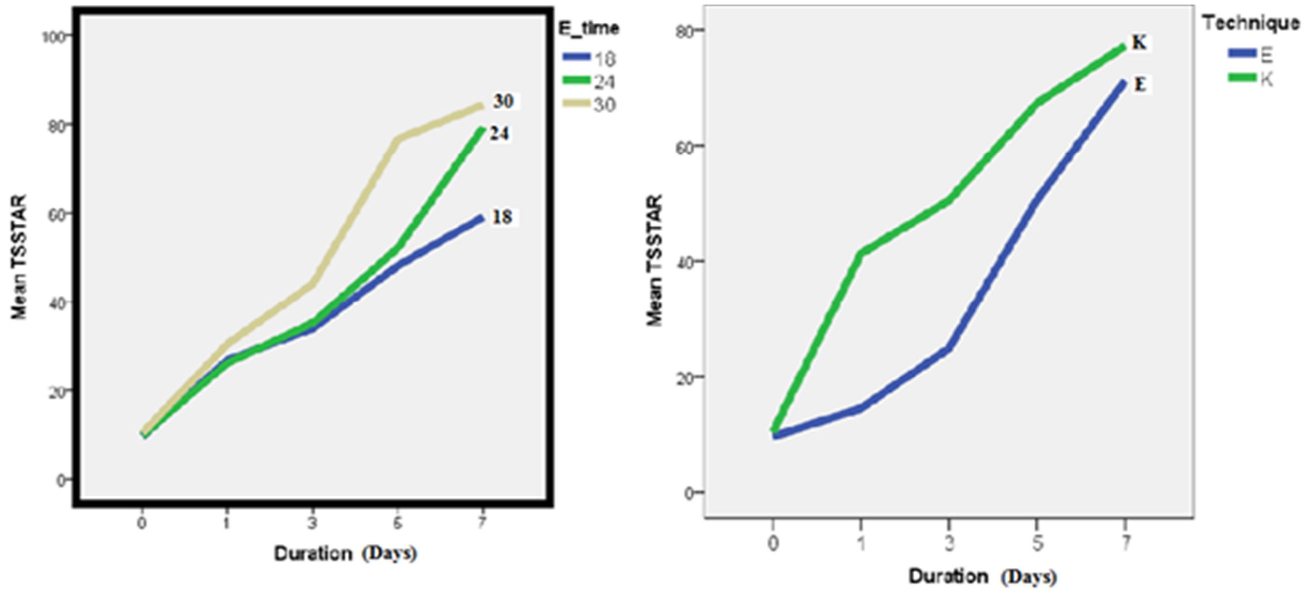

Figure 14. Trend of changes in TSS:TA of banana fruits in response to ripening techniques and exposure periods

The maximum TSS:TA ratio (67 to 81) was recorded on the 7th day of the ripening period across all the treatments under the traditional kerosene smoking ripening system (Table 46). Cultivars treated with the ethrel-based system also showed a similar ratio in TSS:TA on the 7th day under the exposure times of 24 h and 30 h (Table 46). Cultivars treated for 18 hours with the ethrel-based system attained a similar TSS:TA ratio as of the 9th day of the ripening period (Table 47). This increase in TSS:TA ratio was attributed to the increase in the amount of sugars and the parallel decline in organic acids (Dadzie *et al*., 1997). The proportional organic acids increase, which are important in giving a desired sugar-to-acid balance and pleasing fruit taste, usually decline during fruit ripening as they are respired and converted into sugar (Tourky *et al*., 2014).

Table 46. Interaction effect of ripening techniques, exposure times and cultivars on TSS:TA ratio of banana fruits on Day 7

Cultivar	Kerosene smoking			Ethrel		
	18 hrs	24 hrs	30 hrs	18 hrs	24 hrs	30 hrs
Williams I	74.30^{bcd}	81.29^{abcd}	85.10^{abc}	58.41^{ef}	81.34^{abcd}	93.00^{a}
Poyo	67.95^{de}	75.76^{bcd}	79.97^{abcd}	50.66^{f}	74.67^{bcd}	87.30^{ab}
Giant Cavendish	71.41^{cde}	78.68^{abcd}	81.19^{abcd}	22.15^{g}	85.64^{abc}	87.78a^{b}
SE (±)	9.25					
CV (%)	12.46					
LSD (5%)	15.35					

*In each column, means followed by the same letter (s) are not significantly different at ($p \leq 0.05$)

Table 47. Effect of exposure times on TSS:TA ratio of banana fruits treated with ethrel alone on Day 9 and Day 11

Duration (hrs)	Day 9	Day 11
18	67.28[b]	74.17[b]
24	69.69[b]	86.38[a]
30	86.56[a]	90.13[a]
SE (±)	6.71	8.78
CV (%)	9.01	10.51
LSD 5%)	6.71	8.77

*In each column, means followed by the same letter (s) are not significantly different at ($p \leq 0.05$)

Note: Fruits treated with the kerosene smoking-based ripening system completed their marketable shelf life and discarded on the 7[th] day of the ripening period. Thus mean values shown for on the 9[th] and 11[th] day are only for fruits treated with ethrel

pH

pH was expressed as the equilibrium measure of hydrogen ion concentration in the sample fruit juice. The pH value gives a measure of the alkalinity of the sample fruit juice. The pH of the pulp steadily decreased over the ripening period irrespective of treatments (Figure 15).

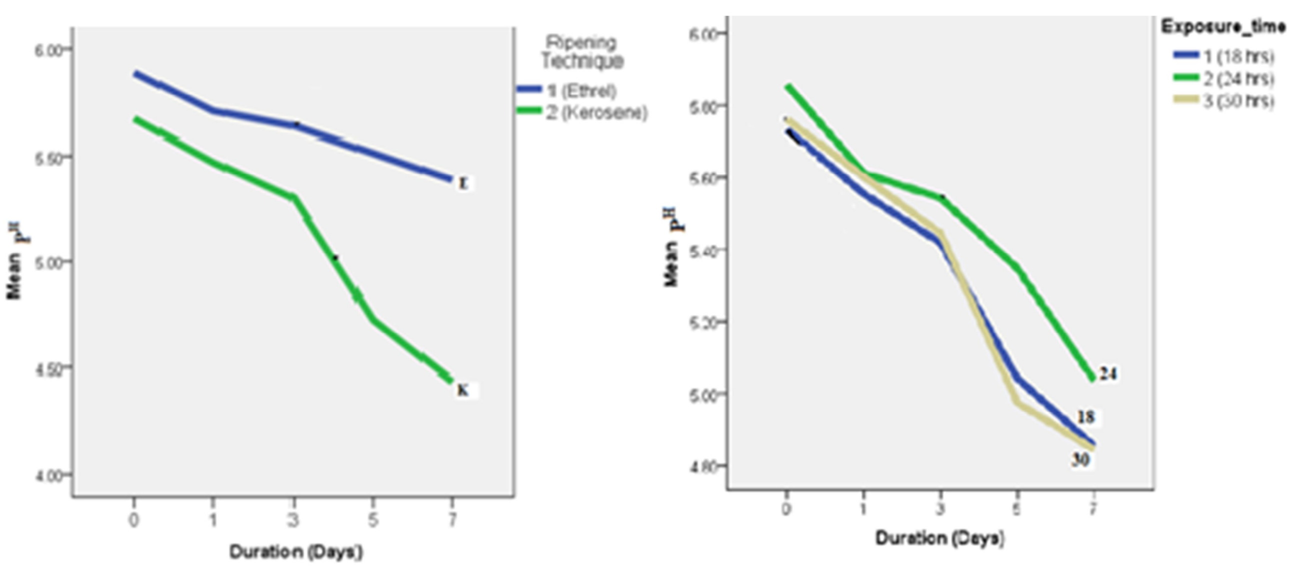

Figure 15. Trend of changes in pH of banana fruits in response to ripening techniques and exposure periods

A two way interaction effect on pulp pH was obtained between exposure times and cultivars on the 7[th]day of the ripening period (Table 48). Significantly ($p \leq 0.05$) low pH was recorded through the kerosene smoking system on the same date (Table 49). On the other hand fruits treated with the ethrel-based system showed similar level of p^H only on the 11[th] day of the ripening time at the exposure times of 24 h and 30 h (Table 50). The decline in pH as ripening progresses is in agreement with the findings of Hernandez et al. (2006) and Zeweter (2008). As ripening advances, titratable acidity increases which results in a decrease of pulp pH (Dadzieet *et al*., 1997). Pulp pH and total titratable acidity are thus important postharvest quality attributes in the assessment of fruit ripening and quality.

Table 48. Interaction effect of exposure times and cultivars on pulp pH of fruits on Day 7

Cultivar	Duration (hrs)		
	18 hrs	24 hrs	30 hrs
Williams I	4.98^{b}	4.89^{cd}	4.86^{de}
Poyo	4.94^{cb}	4.87^{cde}	4.86^{cde}
G. Cavendish	5.20^{a}	4.81^{de}	4.80^{e}
SE (±)	0.07		
CV (%)	1.35		
LSD (5%)	0.08		

*In each column, means followed by the same letter (s) are not significantly different at ($p \leq 0.05$)

Table 49. Effect of ripening techniques on pulp pH of banana fruits on Day 7

Ripening Technique	pH
Kerosene smoking	4.44^{b}
Ethrel	5.39^{a}
SE(±)	0.07
CV (%)	1.35
LSD (5%)	0.04

*In each column, means followed by the same letter (s) are not significantly different at ($p \leq 0.05$)

Table 50. Effect of exposure times on pH of banana fruits treated with ethrel alone on Day 11

Duration (hrs)	pH
18	5.03^{a}
24	4.62^{b}
30	4.47^{b}
SE (±)	0.23
CV (%)	4.9
LSD 5%)	0.23

*In each column, means followed by the same letter (s) are not significantly different at ($p \leq 0.05$)
Note: Fruits treated with the kerosene smoking-based ripening system completed their marketable shelf life and discarded on the 7th day of the ripening period. Thus mean values shown for on the 11th day are only for fruits treated with ethrel

6.3.3. Sensory quality

The data in Table 51 illustrates highly significant differences ($p \leq 0.05$) in mean values among the treatments across all the tested sensory quality parameters. Results also clearly indicate that ethrel treated fruits demonstrated higher mean score values for sensory quality attributes of color (3.85), flavor (3.89), taste (3.80), aroma (3.66) and total acceptability (3.67); other than mouth-feel (3.37). A similar result was reported by Kulkarni *et al.* (2010) that Ethrel at 500 ppm induced uniform ripening without impairing taste and flavour of banana. All the same, Lakshmana *et al*. (2001) reported parallel results that the organoleptic quality of banana ripening treated with 2500 ppm ethrel dip (5 min) at 18^oC-26^oC and 60-70% RH was found optimal for the conversion of starch and acids and possessed better quality attributes in terms of pulp color, taste, aroma, texture, firmness and overall appearance compared to hot water dip (55^oC, 5 min) and including smoking (24 hrs).

Slightly higher mean score value with respect to mouth-feel (3.44) was recorded for the kerosene smoking-based ripening system, which could be related to the similar higher value accounted to it in terms of degree of ripening. The relatively low scores observed in Giant Cavendish fruits under the ethrel-based ripening system, invariable across all the sensory quality attributes, could be attributed to its inability to reach the same ripening stage on the 7^{th}day as the other two cultivars. This situation with Giant Cavendish was likewise manifested through the mean values of most of the other physicochemical parameters tested including total peel color. In addition, the relatively low mean score values accounted to the kerosene smoking-based ripening particularly in terms of color, flavor and aroma, could be attributed to the poor performance of the system in appropriately expressing the natural traits of the fruits. Sarananda (1990) and similar other studies reported that although such traditional smoking techniques of banana using kerosene smoking generally accelerate the ripening process, primarily due to the presence of acetylene (C_2H_2) and ethylene (C_2H_4) in the smoke, they usually render the fruits into lower consumer attractions. This, among other reasons, was similarly attributed to the masked or displaced natural aroma of the fruits by the smoke, poor appearance of smoked fruits, burnt scars and bruises on the peel surface, and increasing the liability of the fruits for microbial infections.

Table 51. Interaction effect of kerosene smoking and ethrel generated ethylene ripening on sensory quality attributes of banana fruits

Treatment	**Means**					
	Color	Flavor	Taste	Aroma	Mouth feel	Acceptability
E 18C1	4.37^{a}	4.00^{bc}	4.30^{a}	3.67^{bcd}	3.83^{b}	4.27^{a}
E 18C2	4.23^{ab}	3.70^{de}	3.80^{c}	3.40^{gh}	3.33^{cde}	3.70^{def}
E 18C3	3.27^{g}	3.70^{de}	3.47^{ef}	3.47^{fg}	3.47^{c}	3.47^{g}
E 24C1	3.77^{c}	3.83^{cd}	3.80^{c}	3.80^{b}	3.73^{b}	3.67^{ef}
E 24C2	4.17^{b}	4.27^{a}	4.20^{ab}	4.10^{a}	3.50^{c}	4.20^{ab}
E 24C3	3.47^{ef}	3.70^{de}	3.73^{cd}	3.67^{bcd}	3.27^{def}	3.60^{f}
E 30C1	4.23^{ab}	4.00^{bc}	3.80^{c}	3.47^{fg}	3.17^{ef}	3.30^{h}
E 30C2	3.63^{cde}	4.10^{a}	3.33^{fg}	3.70^{bcd}	2.80^{g}	3.17^{i}
E 30C3	3.53^{de}	3.67^{de}	3.77^{c}	3.63^{cde}	3.27^{def}	3.63^{ef}
K 18C1	4.20^{ab}	3.63^{e}	4.10^{b}	3.57^{def}	3.77^{b}	3.90^{c}
K 18C2	4.23^{ab}	3.60^{ef}	3.60^{d}	3.50^{efg}	3.33^{cde}	3.67^{ef}
K 18C3	2.83^{ch}	3.13^{h}	3.10^{h}	2.87^{i}	2.67^{g}	2.73^{k}
K 24C1	3.73^{c}	3.63^{e}	3.83^{c}	3.70^{cbd}	3.90^{b}	3.87^{c}
K 24C2	3.27^{g}	3.43^{fg}	3.30^{g}	3.37^{gh}	3.10^{f}	2.93^{j}
K 24C3	3.30^{fg}	3.60^{ef}	3.73^{cd}	3.57^{def}	3.40^{cd}	3.80^{cd}
K 30C1	4.27^{ab}	3.83^{cd}	3.73^{cd}	3.73^{bc}	4.13^{a}	4.10^{b}
K 30C2	3.63^{cde}	3.60^{ef}	3.80^{c}	3.47^{fg}	3.50^{c}	3.73^{de}
K 30C3	3.67^{cd}	3.37^{g}	3.77^{c}	3.30^{h}	3.17^{ef}	3.33^{h}
SE (±)	0.12	0.10	0.10	0.09	0.10	0.06
CV (%)	3.13	2.77	2.65	2.48	2.98	1.69
LSD (5%)	0.20	0.17	0.16	0.15	0.17	0.10
Mean of E:	3.85	3.89	3.80	3.66	3.37	3.67
Mean of K:	3.68	3.54	3.66	3.45	3.44	3.56

In each column, means followed by the same letter (s) are not significantly different at ($p \leq 0.05$); A= Ripening Techniques (K=Kerosene; E=Ethrel); B= Exposure Times (18, 24 &30 hrs); C= Cultivars (C1=Poyo, C2=Williams I & C3=Giant Cavendish);
*= Interaction

Table 52. Correlation among different physicochemical parameters of banana cultivars subjected to different ripening treatments

	Firmness	TSS	pH	TA	TSS:TA	Starch un-staining index	PWL	Peel Color
Firmness	1							
TSS	-.862**	1						
pH	.803**	-.796**	1					
TA	-.819**	.755**	-.734**	1				
TSS:TA	-.819**	.955**	-.686**	.635**	1			
Starch un-staining	-.913**	.904**	-.800**	.842**	.868**	1		
PWL	-.788**	.840**	-.709**	.812**	.792**	.892**	1	
Peel Color	-.771**	.765**	-.600**	.769**	.741**	.820**	.782**	1

**. Correlation significant at P< 0.01 level (2-tailed);

*. Correlation significant at P< 0.05 level (2-tailed).

Note: Starch content was indirectly measured through the iodine-staining method and expressed in terms of the unstained area of the pulp (refer starch data collection procedure under Materials & Methods).

CAHPTER 7: GENERAL SUMMARY, CONCLUSIONS, RECOMMENDATIONS AND OUTLOOK

7.1. Assessment Study on Banana Production Status

Banana production is a major component of the farming systems in the lowland localities of Gamo-Gofa, Bench-Maji and Sheka zones. It plays a considerable role in household nutrition and income generation. On the other hand, the findings of the study revealed that there are huge differences among the production areas in terms experience in banana production, crop management practices, area of land allocated, method of banana production (irrigated or rainfed), spacing and type of planting material used, availability of extension service, and membership to farmer cooperatives/unions. These were uncovered as being the major determinants that affect the yield (productivity and quality) of banana across the study areas. These points out that diligent and timely intervention along this line will unequivocally make a substantial difference in mitigating the problems and enabling farmers to better utilize their banana production potential. Some of the specific interventions that can be recommended along this line include:

- Strengthening research and extension services (improved agronomic practices including sucker and plant density management, regular weeding, farmyard and green-manuring, and harvest maturity determination and harvest systems, etc.),
- Integrated irrigation water development and utilization technologies, soil conservation and gully rehabilitation programs across the catchment areas in Gamo-Gofa zone, and
- Supply of improved and disease free tissue culture plantlets or suckers from regulated central nurseries, control of farmer-to-farmer exchange of suckers in order to minimize the possible risk of pest and disease transmissions.
- Banana producers should use an integrated crop management system to optimize yield and quality

7.2. Assessment Study on Banana Marketing Practices

The current assessment study indicates that banana is the most widely marketed and consumed fruit in Ethiopia, which comprises quite a number of stakeholders across the supply-chain. Similarly, the study revealed that the banana supply chain is facing several limitations and constraints that include highly deregulated marketing practices that result in excessively high price and marketing margin disparities across the numerous channels. The eight major actors identified along the supply chain were also found to invariabily sustain varied costs related to production, transportation, handling, ripening, and marketing and government taxes alongside their respective net marketing margins (profits). Especially banana farmers in Bench-Maji and Sheka zones generally have no clear market information about where and how to sell their bananas. This coupled with the bulky and highly perishable nature of the produce has rendered them to fraud marketing practices by various intermediaries and at times oblige them sell their produce at throwaway prices. The trend has also pressurized some them switch to other less perishable crops such as cereals, spices and coffee.

Conversely, membership of small-scale banana grower farmers in farmer cooperatives/unions was identified as a strength to significantly improve their benefits in terms of their income, availability of market information and farm inputs, development of their technical capacity through organized training and experience-sharing, minimizing the superfluous role and marketing margins of certain intermediaries as well as more organized local and export market participation and negotiation.

In so doing, some of the specific interventions recommended out of the study findings are:

- Organizing farmers, such as in those areas like Bench-Maji and Sheka zones, into farmer cooperatives/unions,
- Introduction of market facilitation and regulatory mechanisms through strong marketing institutions along the supply chain (e.g. the Ethiopian Commodity Exchange Authority) to ensure fair trade prices especially for banana producers,
- Regular training of all banana supply chain actors that help streamline and optimize the functioning of the banana industry in Ethiopia, and
- Improvements in marketing logistics and channel management (i.e. development of cool-chain management systems and market infrastructure such as establishment of delineated wholesale and ripening centers at national and regional markets, establishment of shade-houses and warehouses close to major production areas and farm-gate collection centers for pre-cooling, grading, washing, packaging, application of postharvest treatments, etc.).

7.3. Assessment of Banana Postharvest Handling Practices and Associated Losses

The assessment study on banana postharvest handling practices and losses all the same revealed that despite the concerted effort being made by the government of Ethiopia to promote and diversify its agricultural outputs as well as exports at large, the banana supply chain is generally inefficient facing several limitations and constraints throughout the handling stages.

It is affected by several factors including faulty harvest maturity determination, and rough and rudimentary marketing infrastructure and handling facilities for transportation, packaging, storage, ripening, and loading and unloading. These were similarly identified largely on account of the existing unregulated marketing practices and the absence of strong facilitation and regulatory marketing institutions to streamline and optimize the supply chain at large (e.g. Ethiopian Commodity Exchange Authority). This coupled with the bulky and highly perishable nature of the produce has rendered it to be more liable for various postharvest losses across the supply chain. Under certain worst case scenarios, as observed during the survey in Bench-Maji and Sheka zones, this situation is in return pressurizing some traditional banana producing localities and farmers switch to other less perishable crops such as cereals, coffee and spices.

At a country level at large, the analysis of the survey results indicate that the aggregate postharvest loss of banana is still as high as 45.78%, of which about 15.68% is incurred at farm, 22.05% at wholesale (including transport from farm gate and ripening), and 8.05% at retailer or purchase to end-user sale levels. Of the causes of postharvest loss accounted during banana transport from the farm gate, impact and finger breakage damages purely accounted to 20% while the remaining 80% also included physiological and other mechanical damages like compression, abrasion, bruising and puncturing. Being a delicate and highly perishable crop, market distance, conditions during transportation, duration of transport, storage condition, storage duration, duration of ripening, type of ripening rooms, means of bunch transport, experience in banana marketing and/or handling, etc. were found to be important determinants of the postharvest loss of banana in Ethiopia.

In an attempt to improve the situation, minimize the level of the various postharvest losses stated above and thereby improve the income of all actors across the banana supply chain in Ethiopia, the study has identified and recommended the following (certain) technical interventions areas into the future.

- Establishment of commercial level infrastructure at major farm-gate collection centers for reception and stepwise preparation (pre-cooling, washing, grading, and postharvest treatment applications) of the freshly harvested banana hands,
- Subsequent transportation, ripening and retail distribution of banana hands (instead of bunches) inside returnable standard perforated plastic crates;
- Reinforcement of strong regulatory mechanisms (code of practices) for promoting Good Agricultural Practices (GAP) as well as controlling certain negligence/malpractices during transportation, loading and unloading of fruits as they voyage from farm-gate collection centers to central/regional wholesale markets and retail outlets,
- Introduction and promotion of modern commercial banana ripening techniques using automated ethylene generators with calculated concentrations and exposure time,
- Development and promotion of various value-added products (banana chips, crisps, biscuits, juice, jam, cakes, beer, soft drink, wine, baby foods, etc.),
- Development of regular tailor made training and capacity building programs for all supply chain actors.

7.4. Combined Effects of 1-MCP and Export Packaging on Shelf-life and Quality of Cavendish Banana (Musa spp.)

As part of the overall development policy to promote and diversify agricultural outputs as well as exports, the Ethiopian government has identified banana as a potential export crop to generate hard currency for the country. However, only small trial shipments of about 80 tons were so far reported to Saudi Arabia (Jeddah) in 2012 using temperature controlled (14^{o}C) reefer containers rented from maritime companies abroad.

The trend was planned to continue with an export of 1000 tons of fresh banana per month but could not be realized due to high round trip rental transporatation cost (i.e. 7500-8000 USD per reefer container) as well as other additional miscellaneous inland costs such as custom taxes and service charges for quarantine certification.

As a possible option to recommence the banana exports from Ethiopia, this thesis provides an alternative less costly and less complicated technological alternative that can extend the shelf life of fresh banana fruits to up to 36 days under ambient conditions (22$\pm$1 °C and 80 $\pm$ 5% RH) without significant changes on the major physicochemical quality attributes. This is realized in terms of the recommendation drawn for the use of the highest concentration of 1-MCP (17.5µl/L) in combination with the non-perforated PEP kept within the export standard corrugated cardboard boxes.

Reportedly, the length of time that takes to get the produce to the destination market in Jeddah (Saudi Arabia), from the farm gate in Arba-Minch (Ethiopia), including the 30-35 hours sea voyage, is within the range of 4-5 days. Considering this time period required using reefer containers, the present alternative is believed without any doubt to successfully offset (overcome) the challenges accounted to terminate fresh banana exports from Ethiopia, which basically are related to the various inland and sea voyage costs.

As mentioned earlier, the average manufacturer price of 1-MCP (99.9% purity) cost of 1-MCP is around 18.00 USD/g, which is nearly (equivalent) to 4.5 USD for the recoomended concentration (17.5µl/L) used to treat the fresh banana fruits within a space volume of 4m^3. This elucidates that the recommended option can at least be alternatively (optionally) used whenever the availability and/or expenses for the conventional temperature controlled (14^{o}C) reefer container system deemed unaffordable to export fresh banana fruits from Ethiopia.

7.5. Effect of Traditional Kerosene Smoking and Ethrel on Ripening, Shelf Life and Quality of Cavendish Banana (Musa spp.)

In addition to its ample export potential, dessert banana is the most important fruit crop in Ethiopia. It is most widely consumed and generates quite a substantial income to all those involved along the supply chain. However, being a climacteric fruit, banana, after harvest, needs to undergo through artificial ripening process in order to attain the required organoleptic quality attributes (the bright yellow peel color, firm pulp texture, good flavour, etc.). This is so because natural ripening of mature Cavendish banana cultivars is often known to result in softening with non-uniform, dull, pale yellow and unattractive color.

In so doing, banana ripening in Ethiopia is commercially employed through the use of traditional kerosene smoking systems, which are carried out within what are locally alternatively called “Chella” or “Muket” houses. Such houses are basically airtight rooms inside which different layers of bunches, in some cases hands, are treated using kerosene burners.

However, although such traditional practices are generally known to accelerate the ripening process merely due to the presence of both acetylene (C_2H_2) and ethylene (C_2H_4) gases in the smoke, the fruits are often liable for lower consumer attraction and so being disregarded in many countries, owing to the resultant burnt scars, bruises, poor appearances on the peel, and contamination of the natural aroma of the fruits with the smoke. As a result the technique is being disregarded and replaced by other alternatives in many countries.

Here again, the thesis attempts to provide a relatively low cost, less complicated and more improved banana ripening alternative using ethylene generated from just 10 ml of ethrel solution (ethephon or 2-chloro ethyl phosphonic acid). The technique, when applied at the exposure time of 30 ripening initiation treatment hours, ensured equal ripening efficiency to the conventional kerosene smoking system but with much higher scores in terms of nearly all the basic sensory quality attributes tested (*color, flavor, taste, aroma and total acceptability)*.

In addition, the study has indicated (recommended) that further study may be made to investigate higher concentrations of the ethrel-based ripening system in order to attain the 18 hours exposure time recommended for the kerosene smoking system under similar (ambient) treatment conditions.

Since the average manufacturer, with Freight on Board (FOB) price of ethrel solution, as stated by Zhengzhou Panpan Chemical Co., Shanghai, is within the range of 40-50 USD/L, which is nearly equivalent to 0.40-0.50 USD for the concentration used in the present study (i.e. 10 ml), the technique has also demonstrated itself as a cost effective option (compared to 200 to 300 Birr or 10 to 15 USD with the kerosene smoking system) and addition to being more uniform, reliable and environmental treatment system for banana ripening.

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9. GENERAL ANNEXES

9.3. General Annex Tables

9.3.1. Annex Tables of Chapter 3: Assessment of Banana Production and Marketing

Annex Table 9.1.1.1.. Major sources of irrigation water for banana growers in Gamo-Gofa zone

	Source	Beneficiary Kebeles (villages)	Remark
		A. A/ Zuriya Woreda	
1	Baso river	Ocholo-Lante and Omo -Lante)	-All use traditional diversion dam
2	Dehe river	Ocholo-Lante and Omo-Lante)	-Use modern diversion dam constructed by Vita (NGO)
3	Hare river	Kolla-Shara, Chano-Mille, Chano-Dorga, and Chano-Chelba	-All use traditional diversion dam
4	Sile river	Kanchama-mainly, Kolla-Shele, and Shele-Mella	-Lucy private farm also uses Sile river-by pumping. Farmers use traditional diversion
5	Sego river	ZeyiseAelgo,Kolla-Shelle, Shelle-Mella (and Lucy private farm)	-Lucy private farm also uses Sego river-by pumping. Farmers use traditional diversion
6	Argoba/Wezeka river	Zeyise Wezeka	-All use traditional diversion dam
7	Waso river	Ocholo Lante	-All use traditional diversion dam
8	Kulfo river	Private investors: Omotic farm, Kayiro farm, Amibara farm, Mulat Hailu farm, Mirabu Girma farm, etc.	-All use through the modern diversion dam constructed by Amibara private farm. Farmers also grow some vegetables and other fruits (papaya & mango). Amira farm also grows cotton and maize under irrigation
		B. Mirab Abaya Woreda	
1	Baso river	Omo-Lante and Ocholo-Lante)	-All use traditional diversion dam
2	Raya river	Wanke Wajifo, Kolla-Wolaato	-All use traditional diversion dam
3	Kemie river	Kolla-Barena and Wajifo	-Raya is the major river for Wajifo with Kemie being used to some extent
4	Kolo spring	Doshe	-All use modern diversion dam
5	Ttirattira river	Yayika	-All use traditional diversion dam
6	Lake Abaya	Aelge	- Aelge kebele farmers mainly use Shife river and Lake Abaya
7	Shife or shafe river	Ankober, Molle, Delbo, Aelge, Ugayehu and Faragosa	-All use traditional diversion dam
8	Lake Abaya	Private investors : G/Kirstos, South Industrial PLC, Kedica Enterprise, Shemsu farm, and Minase farm	Investors pump irrigation water from the Lake with an agreed license from the Federal Ministry of Mining and Energy

Source: Mirab-Abaya and Arba-Minch Zuria wereda (district) Agricultural Offices, 2014/2015

Annex Table 9.1.1.2.. List of primary farmer cooperatives that are members of the Gamo-Gofa Farmers Vegetable and Fruit Marketing Cooperative Union PLC, 2014/2015

	Name of cooperative	No. of members			Woreda	Kebele	Major commodity
		Male	Female	Total			
1	Kolla-Shelle F/V/F/P/Cooperative	92	2	94	A/Zuria	Kolla-Shelle	Banana &mango
2	Sile Kanchama F/V/F/P/C	160	6	166	"	Sile Kanchama	Banana
3	Dega-Ochole Dega F/V/F/P/C	16	-	16	"	Dega-Ochole	Applefruit/seedling
4	Abaya-Mille F/V/F/P/C	48	1	49	"	Chano-Mille	Banana & mango
5	Chano-Chelba Aerze F/V/F/P/C	43	6	49	"	Chano-Chelba	Banana &mango
6	Chano-Dorga F/V/F/P/C	26	2	28	"	Chano-Dorga	Banana & mango
7	Gila-Terara F/V/F/P/C	54	2	56	"	Kolla-Shara	Banana & mango
8	Ochole Lante Tenkir F/V/F/P/C	245	50	295	"	Ochole Lante	Banana & mango
9	Zeyise Aelgo Luda F/V/F/P/C	40	-	40	"	Zeyise Aelgo	Banana
10	Kurshato F/V/F/P/C	13	7	20	"	Ochole Lante	Banana (and mango processing)
11	Dega-barana Firafire F/V/F/P/C	156	3	159	M/Abaya	Dega-Barana	Apple fruit/seeding
12	Ankober F/V/F/P/C	8	26	34	"	Ankober	Banana & mango
13	Dalbo F/V/F/P/	20	-	20	"	Dalbo	Banana & mango
14	Wajifo Raya F/V/F/P/C	26	-	26	"	Wajifo Raya	Banana & mango
15	Umo-Lante Tigil Fire F/V/F/P/C	51	-	51	"	Umo-Lante	Banana & mango
16	Molle F/V/F/P/C	15	3	18	"	Molle	Banana & mango
17	Chencha Dega-Firafire F/V/F/P/C	406	70	476	Chencha	Chencha Ketema	Apple fruit/seeding
18	Doko-Kole Derbuse F/V/F/P/C	198	62	260	"	Doko-Kole	Apple fruit/seeding
19	Doko-Shayo Garo-Atikilt F/V/F/P/C	308	70	378	"	Doko-Shayo	Apple fruit/seeding
20	Doyo-Yuyra F/V/F/P/C	227	105	332	"	Doyo-Yuyra	Apple fruit/seeding
21	Ye-Aeze Dega-Firafire F/V/F/P/C	306	35	341	"	Aeze	Apple fruit/seeding
22	Kogo Dega-Firafire F/V/F/P/C	157	53	210	"	Kogo	Apple fruit/seeding
23	Doyo-Yuyra Potato Producers F/P/C	52	10	62	"	Doyo-Yuyra	Potato & apple fruit/seeding
24	Mafona F/V/F/P/C	61	12	73	"	Mafona	Apple fruit/seeding
25	Chilash Area	109	7	116	Boreda	Chilash Area	Apple fruit/seeding
	Total	2837	532	3369	-	-	-

Source: *Gamo-Gofa Farmers Vegetable and Fruit Marketing Cooperative Union PLC, Jan. 2015*

Annex Table 9.1.1.3. Summary of results of the 2012 ATA baseline survey on banana production in Ethiopia

	Parameters	Results	Standard Error (SE)
1	The average production of banana growing households in Ethiopia	557.3 kg	240.9
2	the average yield per banana growing household in Ethiopia	8,759 kg/ha	1,503
3	Percentage of banana plots in Ethiopia receiving inorganic fertilizer	0 %	-
4	Percentage of banana plots in Ethiopia receiving manure by crop	23.5%,	5.8
5	Average price banana grower farmers in Ethiopia receiving from their banana sales	2.4 Birr/kg	0.4
6	Average household revenue obtained by banana growing households in Ethiopia from their banana sales	21.3 Birr/year	5.6
7	Main place where farmers sell banana in Ethiopia	31% on farm, 67% local market , o% cooperatives,2% others	-
8	Main buyers of banana in Ethiopia	2% farmer, 80% trader, 0% cooperative, 18% consumer , 0% others	-
9	Average percentage of farmers who sale their banana under contract agreement	6.1%	3.3

Source: Nicholas et al, 2013.

Where:

ATA= Agricultural Transformation Agency of Ethiopia

9.3.2. Annex Tables of the Analysis of Variance (ANOVA) for Ripening Experiment

Annex Table 9.1..2.1. ANOVA for the Effect of Ripening Techniques, Exposure-Time (hours) and Cultivars on PWL (%)

		Duration (Days)						
		0	1	3	5	7	9	11
Source of variation	df	(Pr > F)	(Pr > F)	(Pr > F)	(Pr > F)	(Pr > F)	(Pr > F)	(Pr > F)
Ripening technique	1	-	0.0025	0.0188	0.1246	0.0554	-	-
E-Time	2	-	0.2464	0.2166	0.1261	0.0362	0.1326	0.3115
Cultivar	2	-	0.3328	0.8377	0.1738	0.1962	0.015	0.2143
Technique*E_time	2	-	0.1716	0.1794	0.865	0.9207	-	-
Technique*Cultivar	2	-	0.3198	0.6055	0.1568	0.018	-	-
E_time*Cultivar	4	-	0.6381	0.4633	0.8936	0.5873	0.1794	0.6185
Techni*E_time*Cultiv	4	-	0.3144	0.3461	0.5188	0.5265		
Error	34	-	-	-	-	-	-	-

Annex Table 9.1..2.2. ANOVA for the Effect of Ripening Techniques, Exposure-Time (hours) and Cultivars on Firmness (N)

		Duration (Days)						
		0	1	3	5	7	9	11
Source of variation	df	(Pr > F)	(Pr > F)	(Pr > F)	(Pr > F)	(Pr > F)	(Pr > F)	(Pr > F)
Ripening technique	1	-	<.0001	<.0001	<.0001	<.0001	-	-
E-Time	2	-	0.9844	0.2163	0.0123	<.0001	<.0001	<.0001
Cultivar	2	<.0001	0.9563	0.51	0.2757	0.0002	<.0001	<.0001
Technique*E_time	2	-	0.1474	0.0335	0.0111	<.0001	-	-
Technique*Cultivar	2	-	0.4369	0.6252	0.0272	<.0001	-	-
E_time*Cultivar	4	-	0.5017	0.3602	0.0237	0.0928	0.0008	<.0001
Techni*E_time*Cultiv	4		0.276	0.474	0.0296	0.1019	-	-
Error	34	-	-	-	-	-	-	-

Annex Table 8.1.2.3. ANOVA for the Efect of Ripening Techniques, Exposure-Time (hours) and Cultivars on Color Index

		Duration (Days)						
		0	1	3	5	7	9	11
Source of variation	df	(Pr > F)	(Pr > F)	(Pr > F)	(Pr > F)	(Pr > F)	(Pr > F)	(Pr > F)
Ripening technique	1	-	-	<.0001	<.0001	<.0001	-	-
E-Time	2	-	-	<.0001	<.0001	<.0001	<.0001	<.0001
Cultivar	2	-	-	<.0001	0.0231	0.3338	0.7114	0.3293
Technique*E_time	2	-	-	<.0001	<.0001	<.0001	-	-
Technique*Cultivar	2	-	-	<.0001	0.396	0.0856	-	-
E_time*Cultivar	4	-		<.0001	0.0248	0.0035	0.243	0.3523
Techni*E_time*Cultiv	4	-	-	<.0001	0.3473	0.8229		
Error	34		-	-	-	-	-	-

Annex Table 8.1.2.4. ANOVA for the Effect of Ripening Techniques, Exposure-Time (hours) and Cultivars on Peel Color*a

		Duration (Days)						
		0	1	3	5	7	9	11
Source of variation	df	(Pr > F)	(Pr > F)	(Pr > F)	(Pr > F)	(Pr > F)	(Pr > F)	(Pr > F)
Ripening technique	1	-	0.0007	<.0001	<.0001	<.0001	-	-
E-Time	2	-	0.0301	<.0001	<.0001	0.0013	0.0433	0.1863
Cultivar	2	0.0254	0.0049	0.5054	0.0699	0.0811	0.3604	0.5643
Technique*E_time	2	-	0.0014	<.0001	<.0001	0.0029	-	-
Technique*Cultivar	2	-	0.095	0.5557	0.0225	0.0414	-	-
E_time*Cultivar	4	-	0.3268	0.5017	0.0738	0.0765	0.2902	0.3427
Techni*E_time*Cultiv	4	-	0.2857	0.7404	0.0099	0.0126		
Error	34	-	-	-	-	-	-	-

Annex Table 9.1.2.5. ANOVA for the Effect of Ripening Techniques, Exposure-Time (hours) and Cultivars on Peel Color*b

		Duration (Days)					
	0	1	3	5	7	9	11
Source of variation	p-value	p-value	p-value	p-value	p-value	p-value	p-value
Ripening technique	-	<.0001	<.0001	<.0001	<.0001	-	-
E-Time	-	0.7585	0.6394	0.1165	<.0001	0.0404	0.1267
Cultivar	0.1573	0.0971	0.0004	0.0251	<.0001	0.2421	0.5536
Technique*E_time	-	0.6994	0.0959	0.2849	<.0001	-	-
Technique*Cultivar	-	0.0132	0.0003	0.0638	<.0001	-	
E_time*Cultivar	-	0.9234	0.7803	0.49	<.0001	0.477	0.4236
Techni*E_time*Cultiv	-	0.0311	0.1168	0.4442	<.0001	-	-
error	34	-	-	-	-	-	-

Annex Table 9.1.2.6. ANOVA for the Effect of Ripening Techniques, Exposure-Time (hours) and Cultivars on Peel Color*L

		Duration (Days)					
	0	1	3	5	7	9	11
Source of variation	p-value	p-value	p-value	p-value	p-value	p-value	p-value
Ripening technique	-	<.0001	<.0001	<.0001	<.0001	-	-
E-Time	-	0.988	0.0005	<.0001	<.0001	0.0164	0.0005
Cultivar	0.0538	0.7631	0.0812	0.3685	<.0001	0.0196	0.0041
Technique*E_time	-	0.0073	0.0057	<.0001	<.0001	-	-
Technique*Cultivar	-	0.9698	0.0874	0.0011	<.0001	-	-
E_time*Cultivar	-	0.4012	0.3882	0.5986	<.0001	0.0259	<.0001
Techni*E_time*Culti	-	0.0791	0.5014	0.3204	<.0001	-	-
error	34	-	-	-	-	-	-

Annex Table 9.1.2.7. ANOVA for the Effect of Ripening Techniques, Exposure-Time (hours) and Cultivars on Pulp Color*a

	Duration (Days)						
	0	1	3	5	7	9	11
Source of variation	p-value	p-value	p-value	p-value	p-value	p-value	p-value
Ripening technique	-	0.8872	0.9096	0.895	0.0475	-	-
E-Time	-	0.9943	0.2409	0.1643	0.0724	0.033	0.5233
Cultivar	0.9114	0.306	0.056	0.1458	0.7439	0.5847	0.2316
Technique*E_time	-	0.0333	0.0358	0.0199	0.0014	-	-
Technique*Cultivar	-	0.5144	0.2202	0.9062	0.8259	-	-
E_time*Cultivar	-	0.3853	0.2428	0.1264	0.2029	0.6363	0.6813
Techni*E_time*Culti	-	0.918	0.1138	0.019	0.3515	-	-
error	34	-	-	-	-	-	-

Annex Table 9.1.2.8. ANOVA for the Effect of Ripening Techniques, Exposure-Time (hours) and Cultivars on Pulp Color*b

	Duration (Days)						
	0	1	3	5	7	9	1
Source of variation	p-value	p-value	p-value	p-value	p-value	p-value	p-value
Ripening technique	-	0.0005	0.0222	0.0107	0.0003	-	
E-Time	-	0.7212	0.456	0.0305	0.0827	0.0404	0.1167
Cultivar	0.3333	0.7037	0.2925	0.8546	0.9812	0.2421	0.5536
Technique*E_time	-	0.054	0.0001	<.0001	0.1386	-	-
Technique*Cultivar	-	0.841	0.7819	0.6314	0.4372	-	-
E_time*Cultivar	-	0.0378	0.321	0.2994	0.2215	0.477	0.4236
Techni*E_time*Cultiv	-	0.5937	0.4969	0.8768	0.9507	-	-
error	34	-	-	-	-	-	-

Annex Table 9.1.2.9. ANOVA for the Effect of Ripening Techniques, Exposure-Time (hours) and Cultivars on Pulp Color*L

	Duration (Days)						
	0	1	3	5	7	9	11
Source of variation	p-value	p-value	p-value	p-value	p-value	p-value	p-value
Ripening technique	-	0.1012	0.3422	0.7187	0.0014	-	-
E-Time	-	0.3784	0.001	0.132	0.1138	0.4277	0.3455
Cultivar	0.07	0.7112	0.2554	0.917	0.444	0.5974	<.0001
Technique*E_time	-	0.0245	0.0502	0.0086	0.8888	-	-
Technique*Cultivar	-	0.964	0.4538	0.7613	0.653	-	-
E_time*Cultivar	-	0.6756	0.034	0.0334	0.6853	0.307	0.468
Techni*E_time*Culti	-	0.5773	0.1526	0.8765	0.2374	-	-
error	34	-	-	-	-	-	-

Annex Table 9.1.2.10. ANOVA for the Effect of Ripening Techniques, Exposure-Time (hours) and Cultivars on Total Pulp Color Change

	Duration (Days)						
	0	1	3	5	7	9	11
Source of variation	p-value	p-value	p-value	p-value	p-value	p-value	p-value
Ripening technique	-	0.0001	0.0002	0.0001	<.0001	-	-
E-Time	-	0.8918	0.5745	0.6821	0.6123	0.4638	0.3078
Cultivar	-	0.2069	0.1423	0.0963	0.6183	0.7024	0.5817
Technique*E_time	-	0.096	0.1746	0.1598	0.2757	-	-
Technique*Cultivar	-	0.0576	0.1909	0.0569	0.1241	-	-
E_time*Cultivar	--	0.6125	0.4358	0.3141	0.9507	0.7695	0.4654
Techni*E_time*Culti	-	0.1351	0.1308	0.1494	0.6971	-	-
error	34	-	-	-	-	-	-

Annex Table 9.1.2.11. ANOVA for the Effect of Ripening Techniques, Exposure-Time (hours) and Cultivars on Peeling Condition

		Duration						
		0	1	3	5	7	9	11
Source of variation	df	(Pr > F)	(Pr > F)	(Pr > F)	(Pr > F)	(Pr > F)	(Pr > F)	(Pr > F)
Ripening technique	1	-	-	<.0001	<.0001	0.0002	-	-
E-Time	2	-	-	<.0001	<.0001	0.0225	0.0233	0.0233
Cultivar	2	-	-	0.0631	-	0.2565	0.2326	0.2326
Technique*E_time	2	-	-	<.0001	<.0001	0.0225	-	-
Technique*Cultivar	2	-	-	0.0631	-	0.2565	-	-
E_time*Cultivar	4	-	-	0.4211	-	0.2495	0.2226	0.2226
Techni*E_time*Cultiv	4	-	-	0.4211	-	0.2495		
Error	34	-	-	-	-	-	-	-

Annex Table 9.1.2.12. ANOVA for the Effect of Ripening Techniques, Exposure-Time (hours) and Cultivars on Starch Unstaining Index

	Duration (Days)						
	0	1	3	5	7	9	11
Source of variation	p-value	p-value	p-value	p-value	p-value	p-value	p-value
Ripening technique	-	<.0001	<.0001	<.0001	<.0001	-	
E-Time	-	0.2351	0.0086	0.0014	<.0001	<.0001	<.0001
Cultivar	-	<.0001	0.0019	0.0086	<.0001	<.0001	<.0001
Technique*E_time	-	0.0406	0.1281	<.0001	<.0001	-	-
Technique*Cultivar	-	0.2095	0.0055	0.1867	<.0001	-	-
E_time*Cultivar	-	0.8229	0.0315	0.1642	0.0003	<.0001	<.0001
Techni*E_time*Cultiv	-	0.0003	0.1458	0.5285	0.0003	-	-
error		-	-	-	-	-	-

Annex Table 9.1.2.13. ANOVA for the Effect of Ripening Techniques, Exposure-Time (hours) and Cultivars on TSS (°Brix)

		Duration (Days)						
		0	1	3	5	7	9	11
Source of variation	df	(Pr > F)	(Pr > F)	(Pr > F)	(Pr > F)	(Pr > F)	(Pr > F)	(Pr > F)
Ripening technique	1	-	<.0001	<.0001	<.0001	<.0001	-	-
E-Time	2	-	0.0524	0.002	<.0001	<.0001	<.0001	<.0001
Cultivar	2	<.0001	0.7963	0.1982	0.7187	0.0013	0.0008	0.223
Technique*E_time	2	-	0.1329	0.0104	<.0001	<.0001	-	-
Technique*Cultivar	2	-	0.2587	0.579	0.8016	0.001	-	-
E_time*Cultivar	4	-	0.7363	0.6808	0.9275	0.0005	<.0001	0.0462
Techni*E_time*Cultiv	4	-	0.4393	0.3847	0.0048	0.0003		
Error	34	-	-	-	-	-	-	-

Annex Table 9.1.2.14. ANOVA for the Effect of Ripening Techniques, Exposure-Time (hours) and Cultivars on TA (%)

		Duration (Days)						
		0	1	3	5	7	9	11
Source of variation	df	(Pr > F)	(Pr > F)	(Pr > F)	(Pr > F)	(Pr > F)	(Pr > F)	(Pr > F)
Ripening technique	1	-	0.0649	0.018	0.0001	<.0001	-	-
E-Time	2	-	0.0003	0.0023	<.0001	<.0001	<.0001	0.0241
Cultivar	2	<.0001	0.2157	0.8973	0.4716	0.0171	0.0031	0.3497
Technique*E_time	2	-	0.0009	0.191	0.0004	0.0018	-	-
Technique*Cultivar	2	-	0.319	0.6916	0.2913	0.2497	-	-
E_time*Cultivar	4	-	0.0878	0.4382	0.7291	0.1662	0.0069	0.1594
Techni*E_time*Cultiv	4	-	0.1861	0.4673	0.0899	0.0902	-	-
Error	34	-	-	-	-	-	-	-

Annex Table 9.1.2.15. ANOVA for the Effect of Ripening Techniques, Exposure-Time (hours) and Cultivars on TSS:TA

		Duration (Days)						
		0	1	3	5	7	9	11
Source of variation	df	(Pr > F)	(Pr > F)	(Pr > F)	(Pr > F)	(Pr > F)	(Pr > F)	(Pr > F)
Ripening technique	1	-	<.0001	<.0001	<.0001	0.0213	-	-
E-Time	2	-	0.2598	0.0151	<.0001	<.0001	<.0001	0.0036
Cultivar	2	0.7359	0.8434	0.0777	0.2813	0.0401	0.0418	0.28
Technique*E_time	2	-	0.0854	0.0031	<.0001	<.0001	-	-
Technique*Cultivar	2	-	0.3618	0.4879	0.6025	0.2722	0.3142	0.971
E_time*Cultivar	4	-	0.8821	0.8376	0.4051	0.4679	-	-
Techni*E_time*Cultiv	4	-	0.2527	0.1855	0.0002	0.0013	-	-
Error	34	-	-	-	-	-	-	-

Annex Table 9.1.2.16. ANOVA for the Effect of Ripening Techniques, Exposure-Time (hours) and Cultivars on pH

		Duration (Days)						
		0	1	3	5	7	9	11
Source of variation	df	(Pr > F)	(Pr > F)	(Pr > F)	(Pr > F)	(Pr > F)	(Pr > F)	(Pr > F)
Ripening technique	1	-	<.0001	<.0001	<.0001	<.0001	-	-
E-Time	2	-	0.5585	0.0005	<.0001	<.0001	0.2014	0.0003
Cultivar	2	0.5533	0.5753	0.3535	0.6956	0.1	0.2432	0.4245
Technique*E_time	2	-	0.2355	0.0013	0.0049	0.0554	-	-
Technique*Cultivar	2	-	0.1521	0.0124	0.2179	0.6813	-	-
E_time*Cultivar	4	-	0.7941	0.4739	0.0495	<.0001	0.8613	0.2015
Techni*E_time*Cultiv	4	-	0.2859	0.7168	0.8993	0.291	-	-
Error	34	-	-	-	-	-	-	-

Annex Table 9.1.2.17. ANOVA for the Effect of Ripening Techniques, Exposure-Time (hours) and Cultivars on Pulp:Peel

		Duration (Days)						
		0	1	3	5	7	9	11
Source of variation	df	(Pr > F)	(Pr > F)	(Pr > F)	(Pr > F)	(Pr > F)	(Pr > F)	(Pr > F)
Ripening technique	1	-	<.0001	<.0001	<.0001	<.0001	-	-
E-Time	2	-	0.2324	0.0491	0.1008	0.3706	0.0369	0.0612
Cultivar	2	0.0486	0.0928	0.0246	0.0033	0.002	0.2116	0.5949
Technique*E_time	2	-	0.0661	0.2838	0.1412	0.0453	-	-
Technique*Cultivar	2	-	0.0367	0.1199	0.9249	0.5491	-	-
E_time*Cultivar	4	-	0.9223	0.7959	0.4903	0.2767	0.3764	0.3467
Techni*E_time*Cultiv	4	-	0.9112	0.3883	0.1402	0.2133		
Error	34	-	-	-	-	-	-	-

Annex Table 9.1.2.18. ANOVA for the Effect of Ripening Techniques, Exposure-Time (hours) and Cultivars on Pulp Drymatter (%)

		Duration (Days)						
		0	1	3	5	7	9	11
Source of variation	df	(Pr > F)	(Pr > F)	(Pr > F)	(Pr > F)	(Pr > F)	(Pr > F)	(Pr > F)
Ripening technique	1	-	0.0035	0.0188	0.2161	0.045	-	-
E-Time	2	-	0.0279	0.0473	0.1211	0.4818	0.2296	0.0853
Cultivar	2	0.3641	0.7635	0.7855	0.9321	0.4846	0.2189	0.6172
Technique*E_time	2	-	0.0244	0.0875	0.027	0.0473	-	-
Technique*Cultivar	2	-	0.4153	0.4306	0.4928	0.6595	-	-
E_time*Cultivar	4	-	0.385	0.3239	0.3326	0.4992	0.9585	0.4482
Techni*E_time*Cultiv	4	-	0.2054	0.5171	0.9056	0.2793		
Error	34	-	-	-	-	-	-	-

9.3.3. Annex Tables of the Analysis of Variance (ANOVA) for Shelf-Life Extension Experiment (1-MCP Experiment)

Annex Table 9.1.3.1. ANOVA for the Effect of 1-MCP and Packaging Materials on PWL (%) of Banana Fruits

		Duration (Days)					
		1	8	15	22	29	36
	df	p-value	p-value	p-value	p-value	p-value	p-value
Packaging	2	0.0124	0.3879	0.0985	0.0018	0.001	<.0001
1-MCP	3	0.0045	0.4264	0.8737	0.8096	0.0965	0.0071
Packaging*1-MCP	6	0.003	0.2022	0.276	0.1367	0.2031	<.0001
error	22						
SE (±)		5.059911	6.854426	7.117406	6.566374	7.403739	2.050226
CV (%)		54.61973	47.10047	41.63579	32.8182	29.61825	6.851002

Annex Table 9.1.3.2. ANOVA for the Effect of 1-MCP and Packaging Materials on Firmness (N) of Banana Fruits

		Duration (Days)					
		1	8	15	22	29	36
	df	p-value	p-value	p-value	p-value	p-value	p-value
Packaging	2	<.0001	0.001	0.006	0.624	0.101	0.108
1-MCP	3	0.003	0.041	0.015	0.001	0.000	0.153
Packaging*1-MCP	6	0.015	0.620	0.178	0.609	0.885	0.035
error	22						
SE (±)		1.095	1.361	1.276	1.895	1.927	2.369
CV (%)		4.862	6.425	6.307	10.127	11.909	16.061

Annex Table 9.1.3.3. ANOVA for the Effect of 1-MCP and Packaging Materials on Color Index of Banana Fruits

		Duration (Days)					
		1	8	15	22	29	36
	df	p-value	p-value	p-value	p-value	p-value	p-value
Packaging	2	0.8912	0.6887	0.0073	0.0021	<.0001	<.0001
1-MCP	3	0.9257	0.9434	<.0001	<.0001	<.0001	<.0001
Packaging*1-MCP	6	0.945	0.8843	0.0328	0.1171	<.0001	0.2698
error	22						
SE (±)		0.489795	0.468718	0.594588	0.627646	0.224733	0.440959
CV (%)		30.40106	29.60327	23.2665	18.82938	5.466485	11.67243

Annex Table 9.1.3.4. ANOVA for the Effect of 1-MCP and Packaging Materials on Total Peel Color Change of Banana Fruits

		Duration (Days)					
		1	8	15	22	29	36
	df	p-value	p-value	p-value	p-value	p-value	p-value
Packaging	2	0.9479	0.8302	0.9587	0.9223	0.9157	0.9304
1-MCP	3	0.0424	0.0089	0.0593	0.0621	0.0347	0.0251
Packaging*1-MCP	6	0.0749	0.4671	0.6791	0.7333	0.7473	0.855
error	22						
SE (±)		10.08324	10.54481	13.10782	13.62878	15.05893	17.07895
CV (%)		61.05915	41.56045	40.78492	36.52197	33.33876	34.47455

Annex Table 9.1.3.5. ANOVA for the Effect of 1-MCP and Packaging Materials on Peel Color *L of Banana Fruits

		Duration (Days)					
		1	8	15	22	29	36
	df	p-value	p-value	p-value	p-value	p-value	p-value
Packaging	2	0.2509	0.2314	0.1159	0.0023	0.1469	0.1463
1-MCP	3	0.4807	0.9008	0.5133	0.3751	0.3049	0.0342
Packaging*1-MCP	6	0.2949	0.5883	0.8428	0.0797	0.7226	0.6617
error	22						
SE (±)		6.143817	3.881659	2.926071	4.159354	6.078844	5.168275
CV (%)		32.68471	17.07474	11.5351	14.40885	19.20646	15.24398

Annex Table 9.1.3.6. ANOVA for the Effect of 1-MCP and Packaging Materials on Peel Color *a of Banana Fruits

		Duration (Days)					
		1	8	15	22	29	36
	df	p-value	p-value	p-value	p-value	p-value	p-value
Packaging	2	0.0355	0.0325	0.0024	0.0053	0.0155	0.1923
1-MCP	3	0.6371	0.8108	0.0069	0.0022	0.0086	0.0278
Packaging*1-MCP	6	0.7507	0.5055	0.471	0.6718	0.8446	0.993
error	22						
SE (±)		1.086522	2.438698	3.690477	4.65057	5.281268	6.130547
CV (%)		-9.359846	-26.88917	-72.3623	-320.729	195.2009	124.8302

Annex Table 9.1.3.7. ANOVA for the Effect of 1-MCP and Packaging Materials on Peel Color *b of Banana Fruits

		Duration (Days)					
		1	8	15	22	29	36
	df	p-value	p-value	p-value	p-value	p-value	p-value
Packaging	2	0.6977	0.2568	0.1898	0.0466	0.1971	0.6662
1-MCP	3	0.919	0.4537	0.1821	0.8113	0.395	0.2045
Packaging*1-MCP	6	0.4651	0.53	0.4544	0.39	0.8833	0.6434
error	22						
SE (±)		11.41035	7.195701	5.783143	5.060483		5.40375
CV (%)		19.42372	11.02086	8.228003	6.793354		6.546766

Annex Table 9.1.3.8. ANOVA for the Effect of 1-MCP and Packaging Materials on Starch Unstaining Index of Banana Fruits

		Duration (Days)					
		1	8	15	22	29	36
	df	p-value	p-value	p-value	p-value	p-value	p-value
Packaging	2	0.7671	0.0033	<.0001	<.0001	<.0001	0.039
1-MCP	3	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
Packaging*1-MCP	6	0.4598	<.0001	<.0001	<.0001	<.0001	0.0195
error	22						
SE (±)		0.321769	0.321769	0.321769	0.297294	0.166667	0.288675
CV (%)		18.98965	14.12645	12.19336	6.52597	2.790698	4.9963

Annex Table 9.1.3.9. ANOVA for the Effect of 1-MCP and Packaging Materials on TSS (^{o}Brix) of Banana Fruits

		Duration (Days)					
		1	8	15	22	29	36
	df	p-value	p-value	p-value	p-value	p-value	p-value
Packaging	2	0.455	0.1565	0.0001	0.0094	0.0244	<.0001
1-MCP	3	0.0023	0.004	<.0001	<.0001	0.0163	<.0001
Packaging*1-MCP	6	0.1393	0.3615	0.021	0.1897	0.0169	<.0001
error	22						
SE (±)		0.187218	0.254505	0.37806	0.75346	0.684902	0.238048
CV (%)		14.71581	17.45176	16.78194	23.44387	15.65491	3.477968

Annex Table 9.1.3.10. ANOVA for the Effect of 1-MCP and Packaging Materials on TA (%) of Banana Fruits

		Duration (Days)					
		1	8	15	22	29	36
	df	p-value	p-value	p-value	p-value	p-value	p-value
Packaging	2	0.9453	0.6496	0.5333	0.6286	0.8615	0.3862
1-MCP	3	0.1159	0.1309	0.0675	0.0376	0.0017	0.4484
Packaging*1-MCP	6	0.665	0.5587	0.6014	0.9701	0.4252	0.4728
error	22						
SE (±)		0.012154	0.011514	0.009495	0.013475	0.015513	0.019988
CV (%)		11.04937	9.39931	7.350825	9.701734	10.30391	11.96646

Annex Table 9.1.3.11. ANOVA for the Effect of 1-MCP and Packaging Materials on TSS:TA of Banana Fruits

		Duration (Days)					
		1	8	15	22	29	36
	df	p-value	p-value	p-value	p-value	p-value	p-value
Packaging	2	0.3162	0.1824	0.0004	0.0155	0.106	<.0001
1-MCP	3	0.0011	0.0054	<.0001	<.0001	0.016	<.0001
Packaging*1-MCP	6	0.1108	0.5007	0.0132	0.117	0.0632	<.0001
error	22						
SE (±)		1.986349	2.918536	3.15228	5.170451	5.630529	5.115549
CV (%)		16.97331	24.31551	17.7788	22.31047	19.10093	12.23382

Annex Table 9.1.3.12. ANOVA for the Effect of 1-MCP and Packaging Materials on pH of Banana Fruits

		Duration (Days)					
		1	8	15	22	29	36
	df	p-value	p-value	p-value	p-value	p-value	p-value
Packaging		0.9161	0.2803	0.1725	0.3802	0.2603	0.4457
1-MCP	3	0.5598	0.8532	0.7129	0.4449	0.2161	0.2995
Packaging*1-MCP	6	0.0819	0.0421	0.506	0.3835	0.9357	0.2553
error	22						
SE (±)		0.056183	0.062563	0.590176	0.551833	0.953608	0.824593
CV (%)		1.051247	1.183537	11.71889	11.19842	21.04837	27.72604

Annex Table 9.1.3.13. ANOVA for the Effect of 1-MCP and Packaging Materials on Pulp Drymatter (%) of Banana Fruits

		Duration (Days)					
		1	8	15	22	29	36
	df	p-value	p-value	p-value	p-value	p-value	p-value
Packaging	2	0.091	0.2394	0.1312	0.1357	0.8198	0.3701
1-MCP	3	0.0172	0.0815	0.0136	0.0011	0.9038	0.0019
Packaging*1-MCP	6	0.0188	0.4158	0.0578	0.123	0.1048	0.5205
error	22						
SE (±)		5.834995	2.242828	1.746309	1.755245	7.87071	11.56007
CV (%)		7.891646	3.021774	2.38984	2.44057	11.68146	22.23091

Annex Table 9.1.3.14. ANOVA for the Effect of 1-MCP and Packaging Materials on Pulp:Peel of Banana Fruits

		Duration (Days)					
		1	8	15	22	29	36
	df	p-value	p-value	p-value	p-value	p-value	p-value
Packaging	2	0.5423	0.1028	0.0279	0.0005	0.0013	0.0038
1-MCP	3	0.3214	0.8122	0.5007	0.0025	0.1175	0.0131
Packaging*1-MCP	6	0.4313	0.2557	0.9806	0.6775	0.1176	0.4882
error	22						
SE (±)		0.105049	0.162757	0.230721	0.20107	0.273446	0.345607
CV (%)		7.343251	10.63386	13.82024	10.78768	13.28483	14.53489

Annex Tables 9.1.4.: Contents of the Questionnaires of the Assessment Study on Banana Production, Marketing, Postharvest Handling, and Postharvest Losses in Ethiopia

Annex 9.1.4.1. Questionnaire 1: Small-Scale Banana Growers

1) Respondent code?
2) Name of respondent?
3) Name of Zone of the respondent?
4) Name of Wereda (district) of the respondent?
5) Name of Kebele (village) of the respondent?
6) Altitude of the respondent Kebele?
7) Agroclimtic condition of the respondent Kebele?
8) Av. rainfall of the respondent Kebele (mm)?
9) Mini.Temp.of the respondent Kebele (^{o}C)?
10) Max.Temp.of the respondent Kebele (^{o}C)?
11) Major soil type of the respondent Kebele?
12) Domnat topogrphy of the respondent Kebele?
13) Av. distance from nearest high way of the respondent house (km)?
14) Gender (sex) of the respondent?
15) Age of the respondent (year)?
16) Educational level of the respondent?
17) Marital status of the respondent?
18) Respondent’s position in the household?
19) Religion of the respondent?

20) Total household size of the respondent?
21) Total male household members of the respondent?
22) Total female household members of the respondent?
23) Male household members less than 15yrs of the respondent?
24) Female household members less than15yrs of the respondent?
25) Male household members of the respondent who are 15 to 65 yrs?
26) Femal household members of the respondent who are 15 to 65 yrs?
27) Male household members of the respondent who are greater than 65 years?
28) Female household members of the respondent who are greater than 65 years?
29) Number of years the respondent lived in the Kebele?
30) Respondent's years of experience in banana production?
31) Respondent's size of land ownership (ha)?
32) Major fruit crops grown by the household of the respondent (in order of importance)?
33) Major cash crops grown by the household of the respondent?
34) Total area allocated for banana by the household of the respondent (ha)?
35) Major banana cultivars grown by the household of the respondent (in order of importance)
36) Type of banana pl.material used by the household of the respondent?
37) Av. weight of banana bunch obtained by the respondent (kg)?
38) Average yield of banana per ha/year (t) obtained by the respondent?
39) Method of banana production of the respondent?
40) Type of banana agronomic Mgnt practices applied by the respondent?
41) Av. Number of banana agronomic mgnt practices applied per year by the respondent?
42) Type of fertilizer used for banana by the respondent?
43) Souce of banana planting material of the respondent?
44) Is there any desuckering practice applied by the respondent?
45) Av.no.of suckers allowed per hill by the respondent?
46) Purpose of banana production by the respondent?
47) Spacing used for banana by the respondent?
48) Are you a member of the Kebele Fruit & Vegetables Marketing Cooperative?
49) Is your Kebele Cooperative a member of the Zonal Fruit & Vegs Marketing Coop.Union?

50) Where do you sell your banana?
51) What are the major problems you face when you sell your banana to farmgate collectors or direct terminal traders?
52) Do you use pesticides for pest and disease control?
53) Do you use herbicides for weeds?
54) How do you control weeds?
55) How do you determine the maturity/harvesting stage of your banana?
56) Whay facilities do you use to harvest your banana bunches?
57) What system of harvesting do you use for your tall banana cultivars (i.e.other than Dwarf Cavendish)?
58) How far is the farmgate selling point of your banana from your farm (km)?
59) How do you transport the bunches to the farmgate selling point?
60) Who often sells the household banana?
61) Do you face problems of not selling your banana?
62) How do you sell your banana?
63) What are the reasons for not selling your banana?
64) What happens to the excess banana fruits/bunches left unsold?
65) Where do you keep the newly harvested bunches before selling?
66) How long do you keep the bunches before selling (day)?
67) Has your income improved ever since you started banana prodn?
68) Do you get any extension service on banana?
69) What is the source of your irrigation water?
70) How do you irrigate your banana?
71) How do you get the irrigation water into your farm?
72) Who built the irrigation structures for you and your fellow Kebele farmers?
73) What are the sources of credit in your area?
74) How are bunches transported to domestic destination markets from your Kebele?
75) How are bunches transported to export markets from your Kebele?
76) How do you ripen your banana at household level?
77) How long does the local banana ripening take (day)?
78) Do you get any market/price information?

79) If yes, what is the source of your market/price information?

80) How is the farmgate banana price determined?

81) What is the usual range of farmgate selling price of banana (Birr)?

82) What is the estimated postharvest loss of banana incurred at harvest (%)?

83) What is the estimated postharvest loss of banana incurred during farmgate transport & storage (%)?

84) What is the estimated aggregate postharvest loss on farm and farmgate level (%)?

85) What are the major cuases of postharvest loss of your banana at the point of harvest?

86) Waht are the major causes of postharvest loss of your banana during farmgate transport & storage?

87) What are the major prevailing problems in banana production in your Kebele?

88) Household marital status?

89) Av.no. of irrigation of banana per year by the respondent?

90) Latitude of the respondent Kebele (N)?

91) Longitude of the respondent Kebele (E)?

Annex 9.1.4.2. Questionnaire 2: Large-Scale (Commercial) Banana Growers

1) Respondent code?
2) Name of respondent?
3) Name of the commercial farm?
4) National Regional State of the farm?
5) Zone of the farm?
6) Wereda of the farm?
7) Altitude range of the farm (m)?
8) Agroclimtic condintion of the farm?
9) Av.Rainfall of the farm (mm)?
10) Mini.Temp.of the farm (^{o}C)?
11) Max.Temp.of the farm (^{o}C)?
12) Major soil type of the farm?
13) Dominant topogrphy of the farm?
14) Av. Distance from nearest high way of the farm (km)?
15) Gender (sex) of the respondent?

16) Age of the respondent (year)?
17) Educational level of the respondent?
18) Position of the respondent in the farm?
19) Number of years since the farm has been establshed?
20) Years of expereience of the farm in banana production?
21) Types of crops grown by the farm (in order of importance?
22) Total area of the farm (ha)?
23) Total area allocated for banana by the farm (ha)?
24) Major fruit crops grown by the farm (in order of importance)?
25) Major banana cultivars grown by the farm (in order of importance)?
26) Type of banana planting material used by the farm?
27) Av. weight of bunch obtained by the farm (kg)?
28) Average yield of banana per ha/year (t) obtained by the farm?
29) Method of banana production of the farm?
30) Type of banana agronomic Mgnt practices applied by the farm?
31) Av.No.of banana agronomic mgnt practices applied per year by the farm?
32) Type of fertilizer used for banana by the farm?
33) Souce of banana planting material for the farm?
34) Is there any desuckering practice applied by the farm?
35) Av.No.of suckers allowed per hill by the farm?
36) Purpose of banana production of the farm?
37) Spacing used for banana by the farm?
38) Where does the farm sell its banana?
39) What are the major problems the farm faces when selling its banana ?
40) Does the farm use pesticides for pests and disases control?
41) How does the farm control weeds?
42) Does the farm use herbicides for weed control?
43) How does the farm determine the maturity/harvesting stage of the banana?
44) What facilities does the farm use to harvest banana bunches?
45) How does the farm harvest the bunches from the tall cultivars (i.e.other than Dwarf Cavendish)?

46) How does the farm transport the banana to the market (selling point)?
47) Does the farm face problems of not selling its banana?
48) How does the farm sell the banana?
49) Where does the farm keep the newly harvested bunches before selling?
50) How long does the farm keep the bunches before selling (day)?
51) Does the income (profitability) of the farm improved ever since it started banana production?
52) What is the source of irrigation water for the farm?
53) How does the farm irrigate its banana?
54) How does the farm get the irrigation water into its farm?
55) How does the farm transport the banana to domestic destination markets?
56) Does the farm export banana?
57) Does the farm practice commercial banana ripening?
58) If so, what ripening technique is used by the farm?
59) Does the farm get any market/price information from any official body?
60) Does the farm also sell its banana at farmgate to local collectors?
61) If yes, what is the source of market/price information?
62) How does the farm determine the selling price of its banana?
63) What is the estimated postharvest loss of banana incurred by the farm at harvest (%)?
64) What is the estimated postharvest loss incurred by the farm during farmgate transport & storage (%)?
65) What is the estimated aggregate postharvest loss on farm and farmgate level (%)?
66) What is the major cuase of postharvest loss at the point of harvest?
67) Waht is the major cause of postharvest loss during farmgate transport & storage?
68) What are the most prevailing problems in banana production?
69) Av.no. of irrigation of banana per year by the farm?
70) Latitude of the the farm (N)
71) Longitude of the farm (E)

Annex 9.1.4.3. Questionnaire 3: Banana Wholesalers/Ripeners at Central and Regional Markets

1) Respondent code?
2) Name of respondent?
3) Respondent’s town?
4) Av. altitude of respondent's town (m)?
5) Latitude of respondent's town?
6) Longtitude of respondent's town?
7) Gender (sex) of the respondent?
8) Age of the respondent (year)?
9) Educational level of the respondent?
10) Marital status of the respondent?
11) Respondnt’s position in the household?
12) Religion of the respondent?
13) Total household size of the respondent?
14) Numb of years the respondent lived in the town?
15) Respondent’s years of experience in banana marketing?
16) From whom do you purchase your banana?
17) Type of banana cultivar that you mostly purchase?
18) Average amount of banana purchase per month (t) by the respondent?
19) What is the average trade tarrif (levy) over the last 2 years charged by the local Revenue Office where the banana is produced/purchased?
20) What is the average purchase price of the new arrival bananas that you pay to the farmgate collector/trader to in the last 2 years (Birr)?
21) How are bananas transported from the purchase site (farmgate) to your base town?
22) What was the average transport cost per ISUZU truck load (50-55 qt) over the last 2 years from the production area to your base town (Birr)?
23) What was the average transport cost per FSR truck load (80-90 qt) over the last 2 years from the production area to your base town (Birr)?
24) How far is the average distance of the banana supply (prodn) area from your base town (km)?

25) How long is the duration of the transport to get the bananas from the prodn area to your home base town (hour)?
26) Where do you keep the newly arrived (puchased) banana?
27) For how long do you keep the bananas before ripening (hour)?
28) What is the banana ripening room made from?
29) What is the major cause of postharvest damage during transporting the banana from the source (farmegate)?
30) What is the estimated postharvest loss during transporting the banana from the farmgate (%)?
31) What is the major cause of damage during unloading the banana into your store?
32) What is the estimated postharvest loss incurred during unloading the banana into your store (%)?
33) What is the major problem (defect) of the newly arrived banana you often encounter before you get it into your ripening room?
34) Which part of the bunch do you consider for ripening?
35) What do you do with the the removed hands of the bunch during ripening?
36) Which part of the hands do you consider for ripening?
37) What is the ripening technique of your banana?
38) How long does the ripening process take (hour)?
39) How many ripening rooms ("Chella houses" or "Muket Bet") do you have?
40) How big is your ripening room ("Chella house" or "Muket Bet") (m.sq.)?
41) How many kerose burners ("Buta Gas") do you use per "chella" house for ripening your banana?
42) Do you use additional heating facility in the ripening room other than kerosene burners"?
43) Do you use any ventillation system in your ripening room?
44) How do you know whether or not the kerosene burners run out of gas?
45) How do you ripen your banana?
46) What is the average stacking layer of bunches you normally consider during ripening?
47) How high is the pile of the dehanded bunches you normally maintaining in the ripening room (if any practice)?

48) How many layers of dehanded fingers do you normally maintain per box (plastic crate) for ripening (if any practice)?
49) How many boxes (plastic crates) do you normally consider in the stacking (overlaying) within the ripening room (if any practice)?
50) What is the major cause of damage or postharvest loss of your banana during the time of ripening?
51) How much is the average physiological weight loss incurred over the period of ripening"
52) What is the overall estimated postharvest loss incurred during the ripening period of your banana (%)?
53) What is the major cause of postharvest loss of your banana during selling it to customers after ripening?
54) What is the estimated postharvest loss incurred while selling your banana after ripening (%)?
55) How do you sell your banana after you withdraw it from the ripening room?
56) How much is the estimated weight loss incurred as a result of the leftover bunch stems after dehanding (kg/qt)?
57) What is the average selling price of your ripened banana in the green stage to retailers (Birr/kg)?
58) Waht is the average selling price of your ripened banana in the final yellow stage to retailers (Birr/kg)?
59) To whom do you sell your banana after ripening (who are your customers)?
60) Are there selling price differences when you sell your banana to your different customers/buyers (i.e. wholesalers, retailers & comsumers)?
61) What is the modality of payment when you sell your bananas to your customers after ripening?
62) Do you also undertake the final ripening or yellowing process?
63) How long does it take to get the final yellow stage after you withrew your banana from the "Chella" house?
64) What after sell service do you provide to your banana customers?
65) Do you export banana to neighboring countries?

66) If yes, which countries do you export your banana to?
67) What is the average selling price of your banana when you export to Djibouti (USD/kg)?
68) What is the average selling price of your banana when you export to Somali-Land (USD/kg)?
69) What is the average selling price of your banana when you export to the Middle-East (USD/kg)?
70) How much is the average export tax charged by the Revenue Office per ton of your banana (Birr)
71) In which way do you export your banana?
72) What transport facility do you use while exporting your banana?
73) What time of the day do you use when you transport your bananas to destination/terminal markets?
74) What are the most frequently faced problems by banana ripeners/wholesalers including yourself?
75) Are you a VAT registered ripener/wholesaler?
76) Do you have your own ripening room ("Chella" house)?
77) What is your role in the actual banana wholesale business?
78) How many "chella" house owners are there in your home town?
79) How many "chella" houses are there in your home town?
80) What is the maximum number of "Chella" houses one owner has in your home town?
81) What other fruits do you whosale besides banana (in order of importance)?
82) Do you also cater other retailers located outside of your base town, if yes, to where?
83) How do you determine whether or not the banana is optimally ripe to withdraw it from the "Chella" house?
84) What time of the day do you start ripening and withdraw the banana from the "Chella" house?
85) Can Cavendish banana ripen uniformly/similarly in the "Chella" house without kerosene treatment?
86) Do you face problems of not selling your banana?
87) Has your income improved ever since you started the banana business?

Annex 9.1.4.4. Questionnaire 4: Banana Retailers at Central and Regional Markets

1) Respondent code
2) Name of the respondent?
3) Respondent's town?
4) Av. altitude of respondent's town (m)?
5) Latitude of respondent's town?
6) Longtitude of respondent's town?
7) Gender (sex) of the respondent?
8) Age of the respondent (year)?
9) Educational level of the respondent?
10) Marital status of the respondent?
11) Respondent's position in the household?
12) Religion of the respondent?
13) Total household size of the respondent?
14) Number of years the respondent lived in the town?
15) Respondent’s years of experience in banana retailing?
16) What other fruit crops do you retail besides banana (in order of importance)?
17) What kind of retailing is your business?
18) From whom do you get (buy) your banana?
19) What type of banana cultivars do you often retail (in order of importance)?
20) Do you also do ripening by yourself?
21) If yes, do you use kerosene burners or other traditional methods of ripening?
22) Average purchase price of your banana over the last 2 years (Birr/kg)?
23) Average selling price of your banana over the last 2 years (Birr/kg)?
24) How are the bananas transported from the purchase site (wholesale) to your selling point?
25) Do you buy green or yellow ripe bananas from the ripeners (wholesalers)?
26) Do you buy the ripe bananas from the ripener (wholesaler) in bunches or hands?
27) How do you do the final ripening (yellowing) of the green ripe bananas you bought from the ripener (wholesaler)?
28) How long do the green ripe bananas take to attain the final marketable (yellow) color?

29) What are the major causes of damage (loss) to your banana from the time you buy it from the ripener (wholesaler) up until you sell it to the consumer?
30) What is the estimated postharvest loss (%) of your banana that occurs from the time you buy it from the ripener (wholesaler) up until you sell it to the consumer?
31) To whom do you sell your final ripened (yellow) banana?
32) Do you make any price differnces when you sell your bananas directly to consumers and the street or open market vendors?
33) How is the modality of payment when you sell your bananas to the street or open market vendors?
34) Household status of the respondent?
35) Who sells the banana from among the family members of the respondent?
36) Do you face problems of not selling your banana?
37) What are the reasons for not selling your banana?
38) What happens to the excess fruits left unsold?
39) Has your income improved ever since you started the banana business?
40) Do you get any market/price information?
41) If yes, what is the source of market/price information?
42) How is the market (selling) price of your banana determined?
43) Do you have access to credit?
44) If yes, where do you get the credit from?
45) What are the major problems associated with your banana retailing business?

Annex 9.1.4.5. Questionnaire 5: Banana Consumers at Central and Regional Markets

1) Respondent code?
2) Name of the respondent?
3) Respondent's town?
4) Gender (sex) of the respondent?
5) Age of the respondent?
6) Educational level of the respondent?
7) Marital status of the respondent?
8) Respondnt’s position in the household?
9) Religion of the respondent?

10) Total household size of the respondent?
11) Number of years the respondent lived in the town?
12) What is your most preferred (favorite) fruit (in order of preference)?
13) Where do you usually buy the banana from?
14) Average amount of banana purchase per month (kg)?
15) Average purchase price of banana over the last 2 years (Birr/kg)?
16) Do you buy green or yellow ripe bananas from the seller/retailer?
17) How do you keep the banana after you buy it?
18) How along do you usually keep the banana after you buy it (day)?
19) What are the major causes of damage to your banana after you buy it from the seller?
20) What is the estimated postharvest loss of your banana after you buy it from the seller (%)?
21) Household status of the respondent?
22) Who usually buys the banana from among your family members?
23) How is the purchase price of the banana often determined?
24) What are the problems often associated with banana when you buy it from the seller/retailer?

Annex 9.1.5. General Annex Section 4: Survey Itinerary

Annex Table 9.1.5.1. Addresses of some banana stakeholders consulted across the survey areas in Ethiopia, 2014/15

Survey location	Date (Ethn. Calendar)	Persons met and discussed with	Responsibility	Telephone No.
Adama	14 /05/06	Ato Shamil	Wholesaler & Ripener	0928-020228
“	“	Ato Zeinu Hussen	“	0912-262371
“	“	Ato Gere	“	0910-267621
Addis Ababa (“Atkilt Tera”	02/4/06	Ato Zerihun Ayele	Wholesaler & Ripener	0911-646554
“	“	Ato Bekele Bereka	“	0911-247829
“	“	Ato Alemu Monja	“	0911-459671
Addis Ababa (ETFRUIT)	4/4/06	Ato Lakew Lachere	Director, Purchase Sales Care Process Directorate	0911-479941, 011-4-163665,
“	“	Ato Simachew Alayu	Ripinening Expert	0910-694618
Assela	13 /05/06	Ato Tesfaye	Wholesaler & Ripener	-
B/Dar	10/04/2006	Ato Tesfaye Ayele,	Wholesaler & retailer	0918-728104
“	“	Ato Wolday G/Aregay & Mebratu G/Aregay	Wholesaler & Ripener	0913-475239; 0936-379377
Debre-Markos	Sun 06/4/06	Ato Dems & Ato Yohannes	Wholesaler & Ripener	-
Dessiee	18-19/4/ 2006	Ato Sindew Shumet	Wholesaler & Ripener	0914-361319
“	“	Ato Demewoz Kindu	“	0912-137755
Woldiya	11/04/ 2006	Ato Haftamu Hagos	Wholesaler & Ripener (ripening done in hands)	0914.166294
“	“	Ato Haftay Fitsum	Wholesaler & Ripeners	0914-096665
Dire-Dawa	01- 02/05/06.	Ato Shibabaw & Ato Taddese Shibabw	Wholesalers	-
“	“	Ato Mebrahtu Kahsay	Dire-Dawa Revenue office	???
Gonder	06 & 09/04/06	Ato Fissiha G/Giorgis	Wholesaler & Ripener	0918-788966
“	“	Ato Jema Abubeker	Wholesaler & Ripener	-

Metema Yohannes Kebele/town	07/04/06	Ato Nigatu Gebeyehu	DA, Crop Devt, Metema Yohannes Kebeke Agric Office	0938-819953
"	"	W/t Worke Taye	DA, Natural Resource Devt, Metema Yohannes Kebele Agric Office	0918-598121
Metema Woreda, Gendawuha town	08/04/06	Ato Melke Tegegn	Hort expert, Agric Office,	0918-121235, melike.tegegne@yahoo.com
"	"	W/t Elsa Desalegn	Hort expert, Agric Office	0920-222264
"	"	Ato Desse Teshager	Extension Work Process Coordinator, Agric Office,	-
Harar	02/05/06	Ato Girma Ayalew	Wholesaler & ripener (ripening expert employee)	0916-043197
Hawassa	24 - 25 / 04/2006	Ato Yisak Dia	Crop Devt. Extension Work Process Acting Coordinator, SNNP Agric Devt Bureau	-
"	"	Ato Zerihun Zena	Crop Devt Agronomist, SNNP Agric Devt Bureau	0936-504797
"	"	Ato Abraham Astatike	Crop Product Quality Control Officer, SNNP Agric. Marketing Cooperative Bureau	0911-384833
"	"	Ato Timotiwos Hayesso	Cluster Team Leader, CSI-SNV Project	0916-823694
"	"	W/o Zeritu Sheshego	Crop Science Research Case Team Coordinator, Hawassa Agric Res Center	0913-385925
"	"	Dr. Elias Urage	Crop Breeder, Hawassa Agric Res Center	0911-852452
"	"	Dr. Alemayehu Challa	Pathologist, Hawassa University College of Agriculture	0913-163096
"	"	Dr. Girma Abera	Horticulturist, Hawassa University College of Agriculture	Girmajibat2006@yahoo.com
"	"	Ato Tamiru Tenna	Officer, Ochole Lante Farmers Cooperative Ripening and Wholesaling Shop	0916-466345
"	"	Ato Tesfahun Mara	Wholesaler & ripener	0920-705574
Hirna & Chiro	01/05/06	-	Local banana retailers (grown in	-

	Eth.C.		Galeti Kebele, West Hararghe zone)	
Jigjiga	4, 5 & 6/05/ /06	Ato Merid Mena	Wholesaler & ripener	0911-098765
“	“	Ato G/Tsadikan Kahsay	Jigjiga Revenue Office	???
“	“	Dr.. Fekadu	Jigjiga Univ.	0910-768360
Tog-Wachale & Tog Wajaale	03/05/06	Ato Kassahun	Wholesaler & ripener	0911-016510
Mekelle	13-14/04/ 2006	W/t Genet Abraha	Wholesaler & ripener	0914-709243
“	“	W/t Birhan Nigus	Sales lady, Ripening & wholesaling shop of the Tekeze-Shiraro- Banana Growers Association/“Mahber” (50 members)	0914-022195
“	“	W/t Tsehay Girmay	Wholesaler & ripener (owner’s sister)	0925-047601
“	“	Dr. Fissiha Hadgu-	Senior Researcher, Tigray Agric. Res. Institute	0931-101157
“	“	Dr. Abraha K/Mariam	Senior Researcher, Tigray Agric. Res. Institute	0914-726239
Tekeze-Shiraro-Banana Growers Association/“Mahber” (50 members)	15/04/ 2006	Ato Tsehaye Negesse	Association/”Mahber” Member	0914-702579
Jimma	05-09/2/07 ???	Ato Worku Tegegn	Wholesaler & ripener	0917-061029
“	“	Ato Wasihun Medina	“	0917-061695
“	“	Ato Amir Mohammed Nur	“	0923-852030
“	“	Ato Abate Suromo	“	-
“	“	Ato Melaku Tegegn	“	-
Bench-Maji Zone	27/09/06	Ato Demeke Tegegn	Acting Dept.Head, Agric Office, Mizan town	0912-057040
“	“	Ato Yitay W/Tinsae	Crop Devt. Expert, Agric Office, Mizan town	0913-845529
“	“	Ato Mulugeta Shanko; Ato Eyasu	Expert , Bench-Maji Zone, Plant	0917-113018, 0911-013227

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Bebeka	29/09/06	Ato Fissiha Teshome	Spice and Hort. Expert, Bebeka Coffee Estate Share Co.	0913-172524
Semen Bench Wereda	02/10/06	Ato Nardos Takele	Head, Wereda Agric. Office, Tebenja-Yaz town	0913-534635
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"	"	Ato Fikru Demelash	DA, Crop Devt., Gorit-ena-Mag Kebele	0921-212799
"	"	Ato Wesa Duka	Administrator, Semen Bench Wereda	-
Tepi (Yeki Wereda, Sheka Zone).	03-5/10/06	Ato Kiros G/Michael	Purchasing & Maintenance Head, Tepi Green Coffee Estate Sh.C	0914-302945
"	"	Ato Gemeda Nemesa	Agric. Devt. V/Head, Tepi Green Coffee Estate Sh.C	0917-828639
"	"	Ato Hussien Yosuf	Coordinator, Crop Devt., Yeki Wereda Agric. Office	0917-482618
"	"	Ato Kassaye Abera	Coordinator, Info & Documentation Unit., Yeki Wereda Agric. Office	-
"	"	Ato Haimanot	Center Mnager, Tepi Agric. Research Center	0910-074818
"	"	Ato Abebe	Division Head, Hort. Research	0912-234905
"	"	W/o Tsehay	DA, Addis-Berhan Kebele, Agric. Office	0931-541191
"	"	Ato Tarekegn	DA, Fide Kebele, Agric. Office	0917-164297
Gojeb	20/11/06	Ato Desalegn	Hort. Agronomist, Gojeb Agri. Dev't Enterprise	0912-377833

“	20/11/06	Ato Desalegn	Farm Manager, Gojeb Agri. Dev't Enterprise	0917-808000
Kobo-Girana	17/04/06	Ato Engda KIROS	Farm Manager, KIWO Kobo-Girana Banana Farm PLC.	0914-313265
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"	"	Ato Gezahegn	Statistician, Arba-Minch University	0913-775043
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"	"	Ato Yimer Keitse	Chairman, Genta-Kanchama, Farmers Primary Marketing Cooperative	0913-054166
"	"	Ato Nebiyu Negash; Ato Andegna Shinale	Admin Head/Accountant & , Project Coordinator, Vita, EU financed NGO on Capacity Building & Sustainable Livelihoods Project,	-
"	"	Ato Admasu Guto	Accountant, Ocholo Lante Tenkir Farmers Primary Marketing Cooperative Office	-
"	"	Ato Genetu Gabisa	Revenue Collection Officer, Ocholo Lante Kebele	-
"	"	Ato Girma Olte	Chairman, Ocholo Lante Tenkir Farmers Primary Marketing Cooperative	-
"		Ato Kayiro Zamba	Owner of Kayiro Banana Farm	-
"	11/10/06	Ato Seifu Koyisha	Manager, Lucy Agric. Dev. PLC	0916-854740
"		Ato Kahsu Atsibiha	Agric. Section Head, Lucy Agric. Dev. PLC.	0913-989936
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			Woreda BoNR, Birbir town	
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"	"	W/o Mulunesh Duka Duma	Work Process Coordinator, Abaya Woreda Woreda Agric Marketing & Cooperatives Office, Birbir town	0911-923166
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"	"	Ato Yibeltal Ejigu	Crop Devt. Expert, BoANR, Omo-Lante Kebele	0911-943602
"	"	Ato Yisak Mathewos (chairman) and Ato Tesfaye Gemberu (Secretary)	Omo-Lante Kebele Fruit Grower Farmers' Primary Marketing Cooperative	-
"	"	Ato Daniel	Farm Manager, G/Kirstos Private Banana farm	
"	"	Ato Kebede Gebisa	Farm Manager, South Industrial PLC Banana Farm	0912-248418
"	"	Ato Temesgen Merdene	Rural Work Entrepreneurship expert, BoNR, Ankober kebele	0913-233676
"	"	W/o Zenebech Girma	Accountant, Ankober Kebele Farmers Primary Marketing Cooperative	0925-547950

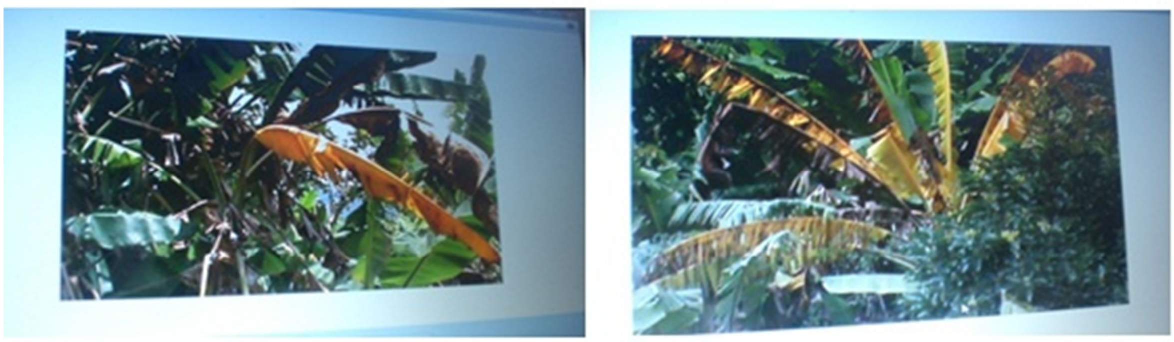
9.4. General Annex Figures

Annex Figure 9.2.1. Partial view of backyard banana production systems in the survey areas

Figure 9.2.2. Partial view of large-scale commercial banana farms in the survey areas

Annex Figure 9.2.3. Local banana cultivars grown in different parts of Ethiopia

Annex Figure 9.2.4. Partial view of rivers and traditional diversion canals used for banana production in Gamo-Gofa zone



Annex Figure 9.2.5. Partial view of symptoms of certain banana diseases observed in Gamo-Gofa zone

Annex Figure 9.2.6. Partial view of banana farm-gate selling (upper left), farm-gate loading (upper middle), transport to regional & central wholesale markets (upper left), unloading at regional & central wholesale markets (bottom left), ripening at regional & central wholesale markets (bottom middle) and green-grocer & street retailing (bottom left) in Ethiopia

Annex Figure 9.2.7a. Banana harvesting with a bushman knife ("gejera"), 8.2.7b & 8.2.7c. Banana bunches being transported from farm to farmgate collection centers by people and donkey-deriven carts

Annex Figure 9.2.8. Farmgate banana collection centers, i.e. roadside (upper left), under tree shade (upper right) and open sun (bottom)

Annex Figure 9.2.9. Banana bunches being loaded at farm gate collection centers and transported to regional/central wholesale markets

Annex Figure 9.2.10. Banana bunches being unloaded, weighed and placed into ripening treatment chambers at regional/central wholesale markets

Annex Figure 9.2.11. Banana bunches (left) and hands (right-ETFRUIT) being treated with kerosene smoking for ripening initiation at regional/central wholesale markets

Annex Figure 9.2.12. Banana ripening chambers at regional/central wholesale markets air-tightly sealed (for 2-3 days) after loading and kerosene smoking for ripening initiation

Annex Figure 9.2.13. Banana retailing along roadsides (vendors), open markets (bottom right) and green grocers (bottom left)

Annex Figure 9.2.14. Banana hands wrapped with newspapers for final consumer level yellow ripening at retailers' level