EFFECT OF HORMONES AND LEAF RETENTION ON ROOTING AND GROWTH OF COFFEE (*Coffea arabica* L.) HYBRID CUTTINGS

M.Sc. Thesis

BY

TEFERI OLJIRRA GERBABA

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Jimma University

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Effect of Hormones and Leaf Retention on Rooting and Growth of Coffee *(Coffea arabica L.)* Hybrid Cuttings

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Teferi Oljirra Gerbaba

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APPROVAL SHEET

School of Graduate Studies

As thesis research advisor, I hereby certify that I have read and evaluated this thesis prepared, under my guidance, by Teferi Oljirra, entitled **Effect of Hormones and Leaf Retention on Rooting and Growth of Coffee *(Coffea arabica L.)* Hybrid Cuttings.** I recommend that it be submitted as fulfilling the thesis requirement.

Ali Mohammed (PhD)

_____	_____	_____
Major Advisor	Signature	Date

Derbew Belew (PhD)

_____	_____	_____
Co-advisor	Signature	Date

As member of the *Board of Examiners* of the M.Sc. *Thesis Open Defense Examination*, We certify that we have read, evaluated the thesis prepared by Teferi Oljirra, and examined the candidate. We recommended that the thesis could be accepted as fulfilling the thesis requirement for the Degree of Master of Science in Horticulture (Coffee, Tea and Spices).

_____	_____	_____
Chairperson	Signature	Date
_____	_____	_____
Internal Examiner	Signature	Date
_____	_____	_____
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DEDICATION

DEDICATED TO THE MEMORY OF MY MOTHER, **MULUNESH LETA UFGA**

STATEMENT OF AUTHOR

First, I declare that this thesis is my bonafide work and that all sources of materials used for this thesis have been dully acknowledged. This thesis has been submitted in partial fulfillment of the requirements for M.Sc degree at Jimma University College of Agriculture and Veterinary Medicine and is deposited at the University Library to be made available to borrowers under the rules of the Library. I truly declare that this thesis is not submitted to any other institution anywhere for the award of any academic degree, diploma, or certificate.

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Name: Teferi Oljirra Signature: ----------

Place: Jimma University College of Agriculture and Veterinary Medicine, Jimma.

Date of Submission: 08 January, 2012

BIOGRAPHICAL SKETCH

The author was born on 27th December 1971 near the town of Shambu Called Kestemaj Beshe, Estern Wollega zone. He attended his elementary school education at Shambu Elementary Schools (1977-1982) and high school education at Shambu Senior Secondary School (1983-1986). He then joined Alemaya University of Agriculture (current Haramaya University) in September 1987 and graduated with a B.Sc. Degree in Agriculture (Plant Sciences) in July 1990.

After graduation he was employed by Teppi coffee state farm which was one of the farms of Coffee Plantation Development Corporation and then which was managed under Ministry of Coffee and Tea Development located in Southern Nation, Nationalities and Peoples Regional State, Shekicho zone and worked as junior agronomist for five years, adaptive research officer for three years and agronomy and protection head for about four years. He was then transferred and promoted to Bebeka Coffee State Farm and worked as Team leader for one year as production operation head for three years and Agricultural Division Head for about five years.

In July 2009, he joined the School of Graduate Studies, Jimma University College of Agriculture and Veterinary Medicine, in July 2009 to continue his studies for Master of Degree in Horticulture (Coffee, Tea and Spices).

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LIST OF ABBREVATIONS AND ACRONYMS

ANOVA	Analysis of Variance
BPEDORS	Bureau of Planning and Economic Development of Oromia Regional State
CBD	Coffee berry Disease
CCRI	Central Coffee Research Institute
CLR	Coffee Leaf Rust
CPDE	Coffee plantation Development Enterprise
CV	Coefficient of Variation
EAFCA	The Eastern African Fine Coffees Association
EIAR	Ethiopian Institute of Agricultural Research
ECX	Ethiopia Commodity Exchange
FAO	Food and Agricultural Organization
FYM	Farm Yard Manure
HARC	Hawaii Agricultural Research center
IBA	Indole-3-butyricacid
NAA	1-naphthaleneacetic acid
JARC	Jimma Agricultural Research Center
JUCAVM	Jimma University College of Agriculture and Veterinary Medicine
LSD	Least Significant Difference
m.a.s.l.	Meters above sea level
MOARD	Ministry of Agriculture and Rural Development
RCBD	Randomized Complete Block Design

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Effect of Hormones and Leaf Retention on Rooting and Growth of Coffee *(Coffea arabica L.)* Hybrid Cuttings

ABSTRACT

Ethiopia is the primary center of origin for Arabica coffee (Coffea arabica L.) which is the single most important cash crop that has been contributing a lion's share to economy. Despite the significant role that coffee plays in the economy of the country, the crop suffers from many production constraints that affect both quantity and quality. This shows that much is expected to increase the production both in quantity and quality. To do this, availability of adequate high quality planting materials that maintain high and sustainable production of good quality crop is needed. The three hybrid coffee varieties (Aba-buna, Melko-CH2 and Gawe) which were released by EIAR can be used for this purpose. However; their multiplication by seed gets difficulty to reach the farmers, Coffee State Farms and the private investors because of the varieties exposure to segregation. On the other hand, hand pollination has also limitations like low fruit set, labor shortage and unfavorable weather conditions which resulted in insufficient planting material. Some methods, such as grafting, budding and tissue culture, need skilled personnel to follow. However, propagation by cutting is one means of reproduction which ensures genetic purity of planting materials especially for those varieties which are exposed to segregation such as F_1 hybrids. The success of rooting in previous work done in Ethiopia did not exceed 89 % under mist propagator and the study did not include other high yielder recently released Ethiopian arabica coffee hybrids, cutting types; and synthetic plant rooting hormones. An experiment was initiated to determine the best rooting hormones (IBA and NAA) which help in establishing a simple and reliable vegetative propagation method using semi hard wood cuttings, without mist propagator in lath house condition by evaluating the rooting ability of hybrid coffee, and to recommend the best practice to the users at, Jimma University College of Agriculture and Veterinary Medicine. Factorial experiment with RCBD was laid down and there were three factors of hybrid, cutting type and hormone of three, two and three levels respectively. Hybrids evaluated were Aba-buna, Gawe and Melko-CH2. Two types of cuttings, six month aged full node with single leaf retention and full node with a pair of leaves retention treated or not treated with indole butyric acid (IBA) and 1-naphthaleneacetic acid (NAA) each with concentration of 400-ppm were also investigated, giving eighteen treatment combinations and replicated three times. Results obtained from the experiment revealed significant difference ($P \leq 0.05$) between treatments for number of cutting sprouted, percent of rooting , number of roots per cutting , root volume, root length, root girth , leaf area, leaf number, shoot number, shoot height, shoot girth, shoot and root fresh weight and shoot, and root dry weight, root to shoot ratio and total dry weight. Percentage of rooting for Gawe hybrid coffee variety treated with both IBA (94.44 %) and NAA (89.81%), and Aba-buna treated with IBA (92.59%) were promising. The results obtained from this study have therefore shown that vegetative production of hybrid coffee(Aba-buna & Gawe) could be attained by application of rooting hormones (IBA and NAA) on semi hard wood single nodal cuttings having a pair of leaf retention and inserting directly in the polybags for successful establishment of cuttings. Further, investigations for different concentrations of hormones, high concentrations for Melko-CH2, cost benefit analysis and use of alternatives for media and hormones, and evaluations of field performance of the cuttings could be suggested as future line of work.

INTRODUCTION

Ethiopia is the primary center of origin for Arabica coffee (*Coffea arabica* L), which is the major agricultural export product (Gole *et al.,* 2002). Coffee is the single most important cash crop that has been and is still contributing a lion's share to the Ethiopian economy (Arega, 2008). Ethiopia is currently the largest in Africa and the third largest Arabica coffee producer in the world, turning out 3.5% of the world coffee (Labouisse *et al* 2008; ICO, 2012). The estimated area of land covered by coffee is about 600,000 hectares, whereas the average annual production amounts to about 270,000 metric tons (EAFCA, 2010).

Coffee is produced in four main production systems: forest, semi-forest, cottage and plantation, which account for 10, 35, 50 and 5%, respectively (Taye and Tesfaye, 2002).The majority (95%) of coffee production in Ethiopia is produced by smallholder farms and there are about 5% of plantation coffee, consisting mainly of state farms, but increasingly also of plantations under private ownership (McMillan *et al.,* 2003; Grundy, 2005).

For Ethiopia, the current contributions of coffee is more than 35% of the country's foreign exchange earnings (ECX, 2008), over 5% of the GDP, 12% of the agricultural output, and 10% of the government revenues (Mekuria *et al*., 2004). It also employs 25% of the domestic labour force (IAR, 1997). About 1.5 million coffee farmers with their 15 million households directly or indirectly depend on coffee for their livelihoods (Petit, 2007; Labouisse *et al*., 2008). About 50% of the production is exported and the rest is consumed locally (EAFCA, 2010). Despite the significant role that coffee plays in the economy of the country, the crop suffers from many production constraints which commonly referred to include the high incidence of Coffee Berry Disease (CBD) and Coffee Wilt Disease (CWD); the shortage of improved cultivars adapted to different localities; poor harvest and post-harvest

practices reducing coffee quality; weak linkages between research, extension services and producers; and adverse climatic factors (drought).

In spite of the fact that Ethiopia is both the centre of origin and diversity of *Coffea arabica*, still coffee production couldn't reach a satisfactory stage both in quantity and quality. The average national coffee yield of Ethiopia is low (710 kg ha^{-1}) (Alemayehu *et al*., 2008). This shows that much is expected to increase production both in quantity and quality. To do this, availability of adequate and high quality planting materials that maintain high and sustainable production of good quality crop is needed. On the other hand, the potential of released Ethiopian hybrid coffee varieties (Aba-buna, Gawe and Melk-CH2) which were superior in yield (24-26q/ha) and resistant to CBD and Coffee leaf rust (CLR) was not exploited and reached the users because of the limitations like low fruit set, labor shortage, unfavorable weather conditions, and meticulous and precision demanding hand emasculation practiced with hybrid seed production altogether contributed to the limited production of hybrid seeds (Vossen, 2002). Therefore, propagation methods that ensure genetic purity of those planting materials need to be addressed.

Several vegetative propagation methods, including grafting, budding, girdling, layering, rooting of hard and soft wood cuttings, and tissue culture (Hartmann *et al.*, 1990) have been tested and employed for *Coffea* species in many coffee growing countries. Some methods, such as grafting, budding and tissue culture, need skilled personnel to follow the procedures while others, such as rooting of semi hard wood cuttings; can be mastered easily with little training. Percentage of success in rooting of cuttings varied from zero to 90 and the time required ranged from two to more than six months (Cambrony, 1992).

Propagation by cuttings (vegetative propagation) is one means of reproduction. Especially for those varieties which are exposed to segregation such as F_1 hybrids, vegetative propagation is the best means of producing true-to-type planting material

to supplement the hybrid seed production through hand pollination. It offers many benefits including ability to regenerate clones, convenience and ease of propagation, combination of genotypes and reduction of length of juvenile period, more vigorous cuttings, disease resistance (for resistant clones), guaranteed genetic stability and improved yields (Hirunpanich, *et al*., 2006). In addition, cuttings remain the most important means of propagating horticultural crop species including hybrid coffee variety.

Hybrid coffee can be propagated by both sexual and asexual means. Sexual seed production needs skill and is very expensive as it may not be practiced at farmer's level. In Ethiopia the use of tissue culture, on the other hand, requires skilled human power to handle laboratory procedures and relatively, high investment costs and sophisticated research work which may also be difficult to apply at farmer's level at least in short run.

Hybrid coffee varieties released by Ethiopian Institute of Agricultural Research (EIAR) (Aba-buna (741 x F-59), Melko-CH2 (7395 x F-59) in 1998 and Gawe (74110 x F-59) in 2002) for medium altitude areas (1500-1750 m.a.s.l) are high yielders (24--26 q/ha) as compared to pure line selections and local types (EIAR, 2008). Despite their superior yield potentials and resistance to CBD and CLR, their multiplication and dissemination had not been realized due to lack of suitable technique of propagation. As a result, these materials have met difficulty to reach the farmers and Commercial Coffee State Farms (Behailu *et al*., 2008).

In order to make these materials available to the farmers the easiest and cheapest way of multiplication of hybrids would be through the use of propagation by cuttings thereby developing clonal gardens. According to Behailu *et al*. (2004), stem cutting rooting experiment conducted at JARC with hybrid Aba-buna showed that mixture of top soil, sand and manure (2:2:1 ratio) as type of media and soft wood single node cuttings with pair of leaves as type of cutting resulted in better (89.27%) rooting ability and (63.3%) survival rate at hardening off stage in propagator with mist spray.

But a lot remains to improve the percentage rooting success and the supply of the improved material to the coffee growers.

The use of different media, under different rooting environment and the use of plant rooting hormones could be used to alleviate the problem based on the plant species.

Auxins control many different aspects of growth and development, as is typical of plant hormones. For instance, they are known to influence the elongation of stems and leaves, the setting and ripening of fruits, and the growth in thickness of trees. They often hasten root initiation; increase the number and percentage of cuttings rooted as well as quality of roots produced per cutting (Newton *et al*., 1992). They also stimulate the formation of new root tips in stem cuttings. Auxins such as naphthalene acetic acid (NAA) and indole butyric acid (IBA) were used for application in rooting experiment of cuttings as they have been observed to be the most effective in initiating root formation for the majority of rooting trials reviewed by Blazich (1988).

The previous study was not comprehensive enough to evaluate rooting performance of released arabica hybrids such as Gawe and Melko-CH2 with cutting having different number of leaves; and treatment with synthetic plant rooting hormones (Auxins) without mist propagator under lath house condition. It was hoped that the success of this method would help reduce infrastructural costs for raising coffee cuttings node for planting and make the technique adoptable by small-scale nurseries. Therefore, the present study was undertaken with the following objectives:

General objective:

To identify the best practice of enhancing rooting performance through application of appropriate rooting hormone and to determine the extent of leaf retention for successful rooting of semi-hardwood cuttings of Ethiopian Coffee (*Coffea arabica* L.) hybrids (Aba-buna, Gawe and Melko-CH2).

Specific objectives:

- To determine the relative rooting ability of released hybrid coffee (Aba-buna, Gawe and Melko-CH2) varieties
- To assess the effect of different extent of leaf retention on the rooting abilities of single nodal semi-hard wood cuttings and
- To evaluate the influence of rooting hormones on rooting of stem cuttings of hybrid coffee varieties

2 LITERATURE REVIEW

In this review some information with regard to the importance of coffee, Ethiopian arabica hybrid coffee varieties, the importance of vegetative propagation of coffee by stem cuttings, rooting hormones, types of cutting, and propagation environment and media are reviewed and documented.

2.1 Importance of Coffee in the World and Ethiopia

Coffee tree belongs to the botanical genus Coffea in the family Rubiaceae. The genus consists approximately of 103 species and a wild Colubrina rbonescens (Farr *et al*., 1989, Davis *et al.*, 2006; 2007). Coffee is the most valuable agricultural commodity in international trade and arabica coffee accounts for 66% of the world coffee market. Ethiopia is currently the third largest arabica coffee producer after Brazil and Colombia (Labouisse *et al* 2008).Coffee is produced in more than 50 developing countries providing income for approximately 25 million smallholder producers (Oxfam 2002b; DFID, 2004), and employing about 100 million people (NRI, 2006). It is also considered as the most important tropical product that contributes almost half of total net exports of tropical commodities (Hallam, 2003). World coffee production in 2006/2007 was forecasted to be 123.6 million bags and world coffee export was forecast at 92.8 million bags (USDA, 2006). In 2005/2006, 52 per cent of world production was accounted by the three main coffee producers (Brazil, Colombia and Vietnam), Brazil supplying about a third of total production (ICO, 2005). The top five consumers are (in order) the USA, Brazil, Germany, Japan and France. World coffee consumption per capita in 2005 was estimated at around 117 million bags (ICO, 2005) and continued to grow in 2009 and, is expected to reach around 132 million bags (approximately 7.9 million metric tonnes) according to the ICO.

Coffee is the most valuable agricultural export commodity of Latin America, Africa and Asia followed by sugar, rubber and cacao (Tefesetewold, 1995). Coffee export amounts to the total value of approximately $ 10 billion annually contributing income to more than 50 nations. The value of coffee ranks second to oi1 as a commodity export earner (Tefesetewold, 1995).

Share of Ethiopia is 3.5 per cent of the global market; the country relies on the crop for a high proportion of its export earnings (ICO, 2010). Coffee plays a significant role in the regional and national, and also contributes to the country's foreign currency earning by more than 35% (ECX, 2008).

Ethiopia is currently the third largest coffee producer worldwide (ICO, 2010). The average annual production amounts to about 270,000 tones (EAFCA, 2010). Coffee is by far Ethiopia's most important export crop (1/3 is exported to Germany). Furthermore, the livelihood of some 15 million people directly or indirectly depends on coffee.

2.2 Ethiopian Arabica Hybrid Coffee Varieties

Hybridization program was launched at JARC in 1978 to support the main selection program. According to Behailu *et al*. (2008), from hybrid vigour study conducted from 1978–1983 at Melko (Jimma), 3 hybrids were advanced to verification. These hybrids together with other two hybrids were tested under verification plot at Gomma-I Coffee State Farm, Metu, and Gera Research Sub-centers. Based on the on-station and verification evaluation results, three hybrids namely, Aba-buna (741 x F-59), Melko-CH2 (7395 x F-59) and Gawe (74110 x F-59) were released in 1998 and in 2002 for medium altitude areas (1500-1750 m.a.s.l). These hybrids were selected for their high yield and resistance to CBD (Coffee Berry Disease) and CLR (Coffee Leaf Rust). Mean yields of the hybrids ranged from 24-26 q/ha on research station and

about 13–20 q/ha in farmers field. They were recommended for medium altitude coffee growing areas of southwestern Ethiopia (Behailu *et al*., 2008).

They hybrids showed a good heterosis over the better parent and check materials (Bayetta *et al*., 2000; 2001). They have 18-41 % yield increase over the standard check selections. They were recommended for medium altitude coffee growing areas of southwestern Ethiopia. Despite the long duration (8 years), since the official release of the hybrids, very small quantity of seeds and seedlings were released, due to mainly the difficulties to produce large quantities of seeds through hand pollination or seedlings through cutting (Behailu *et al*., 2008). However, few seedlings were distributed to CPDE, farmers in Mana and Sekka weredas and to those farmers nearby the research center (Jimma).

2.3 Vegetative Propagation of Coffee by Stem Cuttings

Vegetative (or asexual) propagation is reproduction or multiplication of a new plant from vegetative organs (stem, root, leaf) by cuttings, layering, division and, grafting or budding. It involves mitotic cell division, as a result of which genetic makeup of mother plant remains unaffected (Camborny, 1992).

Arabica coffee is the only polyploid and self-fertile (over 95%) species of the genus *Coffea*, with chromosome number 2n=4x=44, while others are diploid (2n = 2x = 22) and self infertile (Lashermes *et al*., 2000a; Woldemariam *et al.*, 2002; Silvarolla *et al*., 2004).

Coffea arabica is predominantly self-pollinating, and as a result the seedlings are generally uniform and vary little from their parents. In contrast, *Coffea canephora*, *C. excelsa*, and *C. liberica* are self-incompatible and require out crossing. This means that useful forms and hybrids must be propagated vegetatively (Wilson, 1993)

Coffee propagation using seed from natural pollination is associated with inherent uncontrolled genetic variation, in addition to the problems of slow multiplication rate and rapid viability loss of the seeds. The sexual means is also inefficient for propagating Arabica coffee hybrids, due to the problem of segregation in the F_2 generation. Therefore, true-to-type propagation of Arabica hybrids is only possible with hand pollination followed by seed multiplication, or using vegetative propagation techniques, be it macro-propagation (cutting or grafting) or micro propagation (Wondyifraw *et al*., 2008).

Several vegetative propagation methods, including grafting, budding, girdling, layering, cutting and tissue culture (Hartmann *et al.,* 1990) have been tested and employed for coffee species in many coffee growing countries. To follow the procedures of most of these methods, it is expensive and needs skilled persons but rooting of soft wood cuttings can be easily practiced by little training. The other advantage of rooting soft wood cuttings is that it takes only 2-6 months to obtain a planting material with locally available materials (Camborny, 1992). There is an indication that the use of nursery potted media and media mixture is preferred for rooting soft wood cuttings of Arabica coffee to minimize the risk of death due to transplanting shock and during subsequent hardening-off process in propagator and also to minimize the high cost incurred under propagator (Coste,1992; Behailu *et al*., 2004).

Propagation by cutting is the cheapest and most commonly used practice. It has been perfected and can be undertaken almost on an industrial scale. This intensive production system presupposes that the parent clones have previously been selected according to their suitability for producing cuttings. The inter-nodal sections which are used as cuttings develop their roots in a porous substrate in propagators specially prepared as cutting trenches. The rooted cuttings are then planted out in plastic bags, hardened off under shade and in a humid environment then maintained for six to eight months under conventional shading before being transplanted (Cambrony, 1992).

The rapid development of orthotropic shoots is encouraged by the natural habit of the coffee tree which also may be induced by bending the main stem to encourage the growth of upright suckers. Some management practices like weeding, mulching, fertilizing and irrigation can assist to get more and vigorous suckers. It is possible to produce 150-200 cuttings per plant per year which gives 2.7 million-3.6million cuttings per hectare per year (Cambrony, 1992). More success is obtained from those cuttings that are with a node and two leaves than the others (Wamatu, 1993; Hartman *et al*., 2002). In this way, the hybrid vigor and disease resistance of the F_1 Arabica trees could be retained, which otherwise would have lost if multiplied by seed (Wrigley, 1988).

Even though there are several factors that affect the successful rooting of coffee, the most important among others are the rooting medium temperature, relative humidity in the propagator (shade) and the media composition (Hartman, 1997). In Kenya recent findings indicated that less than 50% rooting was produced from single node cuttings with sand and subsoil in 1:1 ratio (Wamatu, 1993).

2.4 Rooting Hormones

In vegetative propagation by stem, cuttings can be taken from shoot of the plants with terminal or lateral, which are capable of developing adventitious roots and then to a complete plant (Hartman *et al*., 1997). However, the rooting success of cutting is dependent on factors such as position of the cuttings on the shoots, rooting medium used, presence or absence of hormone, season when the cuttings were made as well as physical and environmental factors (Wilson,1993).

The diversity of horticultural crops propagated vegetatively throughout the world calls for diversity in the methods utilized in their propagation, often requiring the selection of both established and new techniques based upon the species (or cultivars) to be

propagated and available resources. Changing conditions in the environment of nurseries also call for continuing reassessment of modern nursery processes in order to maintain efficient and profitable operations. The alternative methods of auxin application could be, in at least some part, assist propagators in obtaining good planting material (Blythe and Sibley, 2003).

Auxins as root-promoting chemicals (often referred to as “rooting hormones”): consists of a group of either natural or synthetic plant hormones which promote rooting in plants when used under proper conditions can be used. These include such natural chemicals as IAA (Indole Acetic Acid), and synthetic chemicals such as IBA (Indole Butyric Acid), and NAA (Naphthalene Acetic Acid). They are one of the groups of plant growth regulators (hormones). Some auxins are artificial compounds, but many are produced naturally by plants, especially in young growing parts of the shoot. In nature, they move always from the tip towards the base of shoots, but when applied at the base of cuttings there can be some movement in the opposite direction (Kester *et al*. (1990).

Auxins are most frequently applied to stem cuttings using a basal quick-dip in a concentrated solution, a powder (talc) application, or an extended basal soak in a dilute solution. Liquid formulations offer the advantages of flexibility by allowing dilutions to various final concentrations and uniform application to the base of the cuttings, while powder formulations require no additional preparation prior to use. The most commonly used products include IBA (indolebutyric acid), NAA (naphthaleneacetic acid) and IBA/NAA (indolebutyric acid / naphthaleneacetic acid) combinations in the form of liquid concentrates, water-soluble tablets, and powders (Blythe and Sibley, 2003).

Cuttings of many plant species will form adventitious roots readily when placed under the appropriate environmental conditions. However, cuttings of some plant species are very difficult if not impossible to root. According to Blythe and Sibley (2003),

many of these difficult-to-root plant species can be encouraged to form roots with the use of certain growth regulators, which are sold commercially as "rooting hormones". According to Blazich (1988) auxins naphthalene acetic acid (NAA) and indole butyric acid (IBA) application to cuttings was found to be the most effective in initiating root formation for the majority of rooting trials reviewed.

Auxins often hastened root initiation, increased the number and percentage of cuttings rooted as well as quality of roots produced per cutting (Newton *et al*., 1992). Larsen and Guse (1997) and Kester *et al.* (1990), reported that the most reliable rooting hormone was indolebutyric acid (IBA) although others such as naphthalene acetic acid (NAA) could also be used. According to Kester *et al*. (1990), IBA was probably the best hormone for general use because of being non-toxic to plants over a wide range of concentration levels, although there are reports that it may also be toxic to young/ succulent cuttings of certain species.

IBA has long been used to promote the rooting in cuttings of a wide range of plant species (Hartmann *et al.,* 2002). However, naphthalene acetic acid (NAA) was found to be more effective than IBA in some plants which respond unsatisfactorily to IBA (Hartmann *et al.,* 2002).

Exogenously applied auxin (IBA or NAA) acts on polyamine synthase and IAA oxidase at the gene level (Dietz *et al*., 1990) or through enzyme regulation. Polyamines are considered important in cell division because they stimulate DNA synthesis (Kaur-Sawhney *et al*., 1980). Polyamine biosynthetic enzyme activity and polyamine levels increase before DNA replication (Cohen *et al*., 1984). Moreover, auxin seems to be a universal inducer of adventitious roots.

Although roots may be induced by auxin, wounding is usually required to achieve rooting and it was suggested that wounding-related compounds play a main role in the dedifferentiation phase. Auxin is also involved in gravitropism and phototropism

(Kepinski and Leyser, 2005). These multiple effects across the plant result from its control of cell division, cell elongation and certain stages of differentiation (Davies, 2004).

Tchoundjeu *et al*. (2004) reported a significant role of hormones in stimulating root initiation in stem cuttings of woody plants. The greater ability of IBA to promote adventitious root formation compared with IAA has been attributed to the higher stability of IBA versus IAA both in solution and in plant tissue (Nordstrom *et al.*, 1991).

In an experiment (a two-factor trial with four replications) laid out to determine the effect of different rooting hormones as well as different types of cuttings, all cuttings were dipped in the hormone for 15 minute (Wamatu and King'oro, 1992). In general the influence of the different root promoting growth substance and type of cutting were highly significant and better rooting percentage was obtained with both application of IBA and NAA at concentration of 400ppm and they were not statistically different ($P>0.05$). However, NAA at 400ppm had the best performance compared to others and superiority of split single node to whole single node cuttings was observed.

Anuradha (1993) found that coffee cuttings rooted better using a foliar dip in IBA in comparison to a basal dip. Van Bragt *et al*. (1976) determined that cuttings of various woody species (Berberis, Cotoneaster, Lavandula, Prunus, Pyracantha, and Viburnum) rooted better when immersed in a solution of auxin for two minutes in comparison to a basal dip in an auxin powder. McGuire (1967) compared terminal dips of 1% IBA and basal dips of 0.2% IBA on cuttings of Pachysandra and 11 woody ornamental cultivars (including Acer, Euonymus, Juniperus, Picea, Rhododendron, and Viburnum cultivars). Rooting was significantly greater using the terminal application on three cultivars, lower on one, and not significantly different on the other seven.

Cuttings of several woody species with terminal bud and foliage dipped into an auxin solution rooted as well as cuttings receiving a basal dip (McGuire and Sorensen, 1966). McGuire (1967), found that sufficient auxin applied through a terminal dip entered the foliage and terminal bud of *Ilex crenata* 'Convexa' cuttings, resulting in increased rooting.

Middleton *et al*. (1980), observed that auxins enhance rooting through the translocation of carbohydrate and other nutrients to the rooting zone. Application of Seradix 3 powder increased the level of auxin to enhance the rooting performance of the cuttings. The production of adventitious roots in plants through cell division, multiplication and specialization is also controlled by plant growth substances, especially auxins (Davis and Hassing, 1990).

The success of cuttings propagation was significantly affected by genetic factor (clone), especially on the characteristics of percentage of rooted cuttings, total roots length and number of roots. BP 409 was considered the most difficult clone to be propagated by cuttings (Mawardi and Purwadi, 2004)

In an experiment conducted by Oloyede *et al*. (2004) to evaluate the effect of rooting medium, hormonal treatment and use of half node on the vegetative propagation of *Coffea canephora Pierre ex. Froehner* it was discovered that IBA treatment had significant influence on the root length of rooted cuttings.

Season of collection of planting material (suckers) also plays an important role in successful rooting of cuttings. Suckers collected during rainy season (June-Aug) would ensure more than 90 percent success in rooting (CCRI, 2003).

2.5 Cutting Type, Propagating Environment and Media

The result of an experiment conducted at Jimma Agricultural Research Center to test the effect of different rooting media on rooting ability of F_1 arabica coffee hybrid (Aba-buna) indicated that better rooting percentage (67.5) was obtained with media consisting of top soil and sand (3:1 ratio) and the whole single node cuttings with two full leaves (Behailu *et al*., 2004).

According to Behailu *et al*. (2004), research results in mist propagator at Jimma showed that a combination of single node soft wood cuttings with one pair of leaves taken from orthotropic shoot and rooting media composed of top soil, sand and manure in 2:2:1 ratio was recommended for vegetative propagation of hybrid coffee varieties. According to CCRI (2003), better performance of rooting was observed when single node green wood (semi-hardwood) cutting of 10cm length and 3 to 6 months old were planted in polythene bags with the medium of forest soil, sand and cattle manure (6:3:1).

In another experiment conducted by Wamatu and King'oro (1992), the whole single node cuttings with pair of leaves gave the best results while other types gave comparatively similar results to one another. It was observed that the monthly lifting of cutting for inspection of root did not significantly affect the rooting cutting (Wamatu and King'oro, 1992).

Softwood cuttings are taken from new, soft, succulent spring growth from either deciduous or evergreen species. Softwood cuttings usually root easier and quicker than other cuttings. This type of cuttings generally utilizes the aid of rooting hormones faster than other stem cuttings (Hartmann, 1975). Semi-hardwood cuttings are produced from woody, broadleaf evergreens, and leafy summer cuttings. They are taken from partially matured portion of the plant, usually taken during the summer

growing months just after new shoot development, and partially matured (Hartmann, 1975).

Covering with shade cloth, or enclosing the propagules in polyethylene achieves increased relative humidity, decreased irradiance, and lower air and leaf temperatures. These environmental control methods maintain cell turgor in the absence of functional roots, retaining cell competence to form root initials (Hartmann et al., 1997).

The reason why the rooting of cuttings of different species has slightly different requirements with respect to propagation media, and auxin concentration, is unknown. Studies are in progress at the Institute of Terrestrial Ecology and are aimed at the identification of fundamental principles determining rooting ability in a range of tropical tree species. In this regard it appears that stock plant light/nutrient interactions prior to severance are important (Leakey and Coutts, 1989)

Previous work by the Institute of Terrestrial Ecology (ITE) and its overseas collaborators has applied and improved the design of non-mist propagators for use with a wide range of timber and multi-purpose tree species from both tropical moist forests and semi-arid areas (Leakey and Longman, 1988).

Hartmann and Kester (1983) observed that for good rooting of leafy cuttings, it is essential that they maintain high leaf water potential. The study made by Osei-Bonsu (1992) indicated that coffee cuttings can be successfully rooted directly in polybags with topsoil in the nursery to reduce infrastructural costs.

In Uganda Coffee Industry Ampofo and Osei-Bonsu (1998) noticed that coffee cuttings could be rooted successfully in polybags under raised sheds which did not require the heavy capital investments incurred in Ghana and the additional advantage of the system was that it could be located anywhere with ease.

3. MATERIALS AND METHODS

Description of the study site, experimental material and design used, preparation of rooting media, cuttings and rooting hormones, sticking operation, subsequent after care under lath house condition and data collection techniques are presented in details under this section.

3.1 Description of Experimental Site

The experiment was conducted at Jimma University, College of Agriculture and Veterinary Medicine (JUCAVM) under the lath house condition in 2011 cool season (June to September).

The area is situated in southwestern part of Ethiopia at an altitude of 1710 m.a.s.l, latitude of 7^{o} 41" N and longitude of 36^{o} 50"E. The mean minimum and maximum temperatures in the area are 11.4 and 28^{o}C, respectively. The average total annual rainfall is about 1530mm distributed over seven months (from April to October) and the area experiences a relative humidity of 37.92% and 91.4% as minimum and maximum, respectively (BPEDORS, 2000).

3.2 Experimental Materials

The experimental material include stem cuttings of three hybrids coffee varieties (Aba-buna, Gawe and Melko-CH2) obtained from Gomma-II Coffee State Farm and two rooting hormones (IBA and NAA) which bought from chemical suppliers located in Addis Ababa. The details are given as follows.

3.2.1 Hybrids coffee varieties

Aba-buna: 741 and F-59 (Dessu) are the parents. The hybrid has open type of canopy nature. Mean yields of the hybrid was 23.8 q/ha and 15.5 q/ha on research station and farmer's field, respectively. Cultivar 741 is a CBD resistant Arabica coffee selection. It was originated from Gera and suitable at the altitude of 1900 meter above sea level. The cultivar has open canopy nature and highly resistant to CBD and CLR. Its yield on research station and farmer's field was14.4q/ha and 6.8q/ha, respectively. On the other hand cultivar F-59 was originated from Bonga/Keffa with medium open canopy nature and yields 20q/ha and 14.7q/ha on research station and farmer's field respectively. It is recommended for medium altitude area (below of 1600 meter above sea level) because of high disease pressure at higher altitudes, as it is susceptible to CBD(Behailu *et al*.,2008).

Gawe: 74110 and F-59 (Dessu) are the parents. The hybrid has medium open type of canopy nature. Mean yields of the hybrid was 26.06 q/ha and 19.9q/ha on research station and farmer's field, respectively. Cultivar 74110 is a CBD resistant Arabica coffee selection. It was originated from Bishare/Ilubabor and suitable at the altitude of 1600 meter above sea level. The variety has compact canopy nature and highly resistant to CBD. Its average yield on research station and farmers field was 13.4q/ha and 5.5q/ha, respectively.

Melko-CH2: 7395 and F-59 (Dessu) are the parents. The hybrid has open type of canopy nature. Mean yields of the hybrid was 24 q/ha and 13.1q/ha on research station and farmer's field, respectively. Cultivar 7395 was originated from Yayu/Ilubabor and suitable at the altitude of 1900

meter above sea level. The variety has medium open canopy nature and 70-75% resistant to CBD. Its yield on research station was 16.3q/ha.

3.2.2. Rooting Hormones

Indole-3-butyric acid (IBA): is naturally occurring, but at very low abundance. It works by being converted to IAA by the plant. It is commonly found in commercial rooting compounds

Naphthalene acetic acid (NAA): is a purely synthetic auxin. It is chemically similar to IAA in structure but is a more effective auxin in promoting rooting. It is commonly found in commercial rooting compounds and is often combined with IBA.

In this experiment IBA and NAA were used and applied to stem cuttings using an extended basal soak in a dilute solution for 15 minute (Wamatu and King'oro, 1992).

3.2.3 Preparation of cuttings

Clonal gardens of coffee (*Coffea arabica* L.) hybrids (Ababunna, Gawe and Melko-CH2) were established in 2006 at Gomma-II Coffee State Farm, which was managed under Coffee Plantation Development Enterprise (CPDE) and located 50km west of Jimma town at an altitude of 1400-1750 m.a.s.l (Plate 1 and Plate 2)

Stem cuttings of these three coffee hybrids were prepared from six months old suckers, which were collected on 1st June 2011 from mother bushes in clonal garden early in the morning. The cuttings were wrapped with wet sack and placed in bucket with little water at bottom and transported to JUCAVM (Plate 3).

Seven centimeter long single node semi-hard wood cuttings with two types of leaf retention (single leaf and pair of leaves) were prepared using alcohol-disinfected sharp cutter (secateur) and used in the experiment. While preparing the cuttings, the top portion was given a horizontal cut just above the node while the bottom portion was given a slant cut.

3.2.4 Potting mixture

The potting mixture used for rooting of cuttings in the present study was slightly modified from what has been recommended for coffee seedlings raised by seeds. It was 6:3:1 **(**CCRI, 2003**)** mixture of sieved jungle soil, coarse river sand and well decomposed FYM or compost. For filling the nursery mixture, Polyethylene bags of 22 x 16cm size and 150 gauge thicknesses with adequate number of holes at the bottom-half were used to fill the rooting medium mixture. They were then arranged in rectangular beds of 1.2m width and 7m length prepared using wooden trenches (Plate 4 and Plate 5).

Cow dung was collected from the dairy farm of the JUCAVM and buried in pits having 100cm length, 50cm width and 80cm depth at JUCAVM composting site. The pit was lined with polythene sheet to prevent contact of the material with soil. The dung was mixed after four weeks in order to enhance the composting process by breaking up the composting materials. After two months, pit was opened and the composted cow dung was dried and sieved through a 2mm mesh (Harold *et al*., 1994). Then the sieved composted cow dung was mixed with forest soil and sand which was also pre-sieved through 2mm mesh, at the ratio of 6:3:1(Jungle soil : Sand: Cow dung).

The growing media used for rooting was placed in a lath house and kept moist by covering with plastic sheet and watering two times a day for the 1st two weeks and

then once per day based on Psychrometric conditions determined by measuring relative humidity and temperature measurements taken using psychrometer (Plate 6). Before insertion of cuttings the media was tested in the soil laboratory of JUCAVM for physico-chemical properties (Appendix Table1) to know the composition of the in the rooting environments.

3.2.5 Preparation of coffee rooting hormones and sticking

In this experiment, powders of IBA (indolebutyric acid) and NAA (naphthaleneacetic acid) were prepared first put in ethanol (75%) and then diluted with distilled water to a uniform concentration of 400 ppm (Wamatu and King'oro, 1992).

While applying the hormones, basal end soaking method was used and, thus, prepared cuttings were left standing in the prepared respective hormone solution with their basal end (1–2cm) for 15 minutes (Wamatu and King'oro, 1992). This method was adopted as it is reported to be the most economical as a limited amount of material can be applied directly to the basal region of the cuttings where adventitious root initiation and development take place (Blythe and Sibley, 2003).

Prepared cuttings were then immersed in a diluted alcohol (50ml ethanol +50ml water) for one minute in order to prevent the risk of fungal attack. Later, the basal slant cut portion of the cuttings was treated with the respective hormone solution (400 ppm IBA or NAA) for about 15 minutes (Wamatu and King'oro, 1992) before inserting into the rooting medium. On the other hand, cuttings in the control treatment(No hormone), were equally treated with distilled water. Soon after treatment and insertion in the potted medium cuttings were thoroughly watered. The frequency of watering was once per a day early in the morning (6-7 AM). Inserted cuttings were covered with white plastic sheet over a supporting frame to maintain high relative humidity (approximately 85% to 95% or more) as measured by psychrometer (Model 8706N and made in China). All other nursery management

activities were carried out equally to all experimental units as per the recommendation.

3.2.6 Aftercare of stem cuttings

Cuttings were watered once a day during morning hours. Relative humidity and temperature were measured by using psychrometer two wise per day. The trench was always kept covered by the polythene sheet to avoid exposure of cuttings to outside atmosphere and rain, except during watering, supervision and date collection.

Inside the trench, hygiene was insured by removing weeds, fallen leaves and dead cuttings to obtain maximum success. Excess watering was also avoided in order to avoid rotting of cuttings and delaying of the rooting process.

3.3 Experimental Design and Treatments

A 2 x 3 x 3 factorial experiment (two leaf retention types, three hybrids varieties and three two hormone types and distilled water) was laid out using a Randomized Complete Block Design (RCBD). The experiment consisted of 18 (3 x 3 x2) treatment combinations with three replications (Table 1).

Table 1 Treatment combinations

Coffee Hybrids	Leaf retention/Cutting type	Hormones	Treatment combinations
A	L1	0	AL10
		IBA	AL1IBA
		NAA	AL1NAA
	L2	0	AL20
		IBA	AL2IBA
		NAA	AL2NAA
G	L1	0	GL10
		IBA	GL1IBA
		NAA	GL1NAA
	L2	0	GL20
		IBA	GL2IBA
		NAA	GL2NAA
M	L1	0	ML10
		IBA	ML1IBA
		NAA	ML1NAA
	L2	0	ML20
		IBA	ML2IBA
		NAA	ML2NAA

Hormones = No hormone or distilled water (0), IBA and NAA

Leaf retention/Cutting type =One leaf (L1) and Two leaves (L2)

Coffee Hybrids (Variety) =Aba-buna (A), Gawe (G) and Melko-CH2 (M)

The number of polythene bags for one treatment pre replication was 18. The total number of polythene bags per replication was 324 (3 hormones x 3 hybrids x 2 leaf retention levels x 18 cuttings per treatment). Hence, the total numbers of cuttings used in three replications for three hybrids (Aba-buna, Gawe and Melko-CH2) were 972 (324 x 3). Randomizations for treatment combinations were done independently in the lath house based on the principle of randomization (SAS.9.2).

3.4 Data Collection

Data were destructively collected after 120 days of planting using eight randomly selected sample cuttings from each treatment and the average was taken. At the end of the study, cuttings were separated in to root and shoot parts and evaluated for the different parameters as pre-planned. The parameters measured and the methods used to measure each are presented as follows;

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Percentage of rooted cuttings (%): The percentage of cuttings that rooted was calculated after counting all healthy cuttings per treatment which showed at least one well developed root without using sampling.

Root number: Polythene bags containing the roots of seedling were cut vertically and the soil was removed thoroughly from the root by immersing it into a bucket of water and roots were separated carefully from the media still being in water. The roots were subsequently washed with clean water and dried with water absorbent cloth; then the root number was counted by using hand lens or simply through naked eye. Then the newly growing roots were counted and the average was taken.

Root girth (mm): The diameter of all primary roots per cuttings was measured by digital caliper (Model Fowler, USA) 2cm from the point of emergence and the average was taken.

Root length (cm): the length of all the roots in the sample cutting was measured separately from the point of emergency to the tip by using a ruler and the average was taken.

Root fresh weight (g): The weight of all the roots of a sample cutting was measured individually by using sensitive balance (Model CTG-6H+, USA) and the average was worked out and recorded in grams.

Root volume (cm^3): Root volume was measured by water displacement method. Water was filled in a known volume of graduated cylinder and roots were immersed. The volume of water displaced due to the immersion of roots was taken as root volume.

Root dry weight (g): After drying the roots in an oven drier for about 24 hours at 70 ^{0}C, to a constant weight the average weight of dried roots was taken using a sensitive balance and the average was calculated for each treatment.

Shoot Length or height (cm): The length of each newly developed shoot was measured from the point of attachment on the cutting (stem) to the tip of the shoot using a ruler and the average was taken for each treatment.

Shoot fresh weigh (g): The weight of newly growing shoots was measured right after harvesting by using sensitive balance and the average weight was taken for each treatment.

Shoot dry weight (g): After drying the shoot part in an oven for about 24 hours at 70 ^{o}C, to a constant weight the weight of dried shoots was measured by using sensitive balance and the average value was taken for each treatment.

Shoot number: The newly growing shoots (suckers) were counted for each sample cutting and the average was taken for each treatment.

Shoot girth (mm): Girth or stem diameter all primary shoots (suckers) per cuttings were measured by digital caliper (Model Fowler, USA) at 2cm from the point of emergence and the average was taken for each treatment.

Leaf number: The newly growing leaves were counted for each sample cutting and the average was calculated for each treatment.

Total leaf area (cm^2): The leaf area developed by the newly initiated shoots was measured with a leaf area meter (Model AM 200, England) and recorded and the average was used for analysis.

Root fresh weigh (g): The weight of the newly emerged roots was taken before drying using sensitive balance (Model CTG-6H+, USA) and the averages weight was taken.

Root dry weight (g): After drying the roots in an oven for about 24 hours at 70 ^oC, the average weight of dried roots was taken using sensitive balance and the average was taken.

Root to shoot ratio: Root to shoot ratio was determined by dividing dry weight of roots to shoots of each sample cutting and the average was calculated for each treatment.

Total dry matter (g): After drying the whole plant parts (shoots plus roots) in an oven drier for about 24 hours at 70 ^oC, the weight of dried whole plant parts (shoots plus roots) was measured by using sensitive balance and the averages value was taken for each treatment .

3.5 Data Analysis

First data were checked for meeting all assumption for ANOVA. Then a SAS Version 9.2 statistical computer package was used to analyze the data. The experiment was arranged in 2x3x3 factorial combination in Randomized Complete Block Design (RCBD) with three replications.

The model of the design was:-

$$\mathbf{Yijk = \mu + Ai + Bj + (AB)ij + Ck + \beta + (AC)ik + (BC)jk + (ABC)ijk + \sum ijk}$$

Where: $i=1, 2\ldots,a;$ $j=1, 2\ldots.,b;$ & $k=1, 2\ldots,c$

- Yijk is the observation of the ith, jth & kth treatment (response variable)
- $\boldsymbol{\mu}$ is the mean,
- Ai, Bj &Ck is the treatment effect of the ith, jth &Kth treatment,
- ABij is interaction of Ai and Bj treatment
- ACik is interactions of Ai and Ck treatment
- BCjk is interactions of Bj and Ck treatment
- ABCijk is interactions of Ai, Bj and Ck treatment
- β is the replication or block effect, and ∑ijk is the experimental error.

The significance of the difference between the treatment mean was further confirmed by MSTATCS. For those significant treatment mean differences, mean separation by using the LSD value at $P \leq 0.05$ was utilized.

4 RESULTS AND DISCUSSION

4.1 Percent Rooting of Stem Cuttings

As presented in Appendix Table 2, the analysis of variance for percent rooting indicates that the three way interactions and two way interaction between hybrids and leaf retention were not significant (P>0.05). However, there were apparent interaction effects between leaf retention and rooting hormone and hybrid coffee varieties and rooting hormones (Plate 7).

Significantly higher percent rooting (97.53 %) was observed for cuttings having a pair of leaves and treated with IBA, followed by those treated with NAA (88.88%), while the lowest value (76.24 %) was recorded for cuttings with a single leaf and treated with no hormone (Table 2, Plate 8 and Plate 9). Moreover, single leaf hormone treated cuttings were not statistically different (P> 0.05) from those untreated cuttings with single leaf and a pair of leaves.

The performances of IBA and NAA for cuttings a pair of leaves were found to be superior by about 28 and 17 percent respectively over the single leaf retention with no hormone (distilled water) treatment. These results obviously indicate the advantage of hormone, especially IBA, treatment and retention of pair of a leaves in promoting root developement coffee stem cuttings.

This might be probably due to the presence of more leaf area for photosynthesis which encourages more rooting as compared to cuttings with one leaf when interacted with exogenous hormones Moreover, the presence of Indole-3-butyric acid which naturally in plants at lower concentrations Heinz *et al*. (1962) and Chalapathi *et al.* (2001), supplements the exogenous applied hormones in favouring rooting and might

have more improved the rooting capacity of the cuttings. The high variability in the behavior of cuttings to root could be attributed to the physiological condition of the cuttings. This includes the presence, or lack of, endogenic root inhibitors or promoters, the reserve food material within the cutting, etc.

With regard to the rooting ability of the three hybrid varieties, significantly the higher value (94.44 %) was observed for Gawe cuttings treated with IBA which however was statistically at par with Aba-buna treated with same (92.59%) and Gawe with NAA (89.81%) while the lowest value (76.85%) was registered from cuttings of Aba-buna in no hormone (distilled water) being statistically at par with Gawe treated with no hormone (79.18%), Aba-buna with NAA (82.12%), Melko-CH2 with no hormone(80.55%), Melko-CH2 with IBA (79.63%) and Melko-CH2 with NAA (81.48%)(Table 3). The performance of Gawe and Aba-buna cuttings treated with IBA was observed to vary by 23 and 20 percent, respectively over the hormone untreated (distilled water) cuttings of Aba-buna.

The most probable reason for high percentage rooting of Gawe could be its genetic expressin, more responsive to rooting hormones than did Aba-buna and Melko-CH2. Hence, the synergy between its good inherent characteristics and the influence of IBA on DNA synthesis (Kaur-Sawhney *et al*., 1980; Cohen *et al*., 1984) and adventitious root regeneration can be regarded as the main contributing factor. On the other hand, the response of Melko-CH2 toward rooting hormone was found to be poor. This is probably due to the presence hard sclerenchyma ring and greater proportion of parenchymatous gaps in the sclerenchyma sheath which is difficult for penetration of root primordial during rooting.

Table 2 Interaction effects of leaf retention and rooting hormones on percent rooting ability of hybrid coffee cuttings

Leaf retention	Hormones	Percent rooting
One leaf	No hormone	76.24c
One leaf	IBA	80.24c
One leaf	NAA	80.06c
Two leaves	No hormone	81.48c
Two leaves	IBA	97.53a
Two leaves	NAA	88.88b
LSD (5%)		6.530
CV (%)		8.11

Means followed by the same letter(s) are not significantly different (P≤0.05)

The result of the present investigation is in agreement with the work done by Wamatu and King'oro (1992) who reported that percent of rooting was significantly affected by IBA and NAA but these hormones were not significantly different for percent of rooting when single node cuttings of Ruiru-11 were rooted. It is also in alignment with the work of Laubscher and Ndakidemi (2008) have also indicated that the highest rooting and survival rate of cuttings was recorded in the IBA treatment. Similarly, Akwatulira *et al*. (2011) have shown the influence of different rooting media and indolebutryic acid (IBA) concentration on root and shoot development in stem cuttings of *Warburgia ugandensis* and revealed that callusing, root and shoot development were significantly ($p<0.05$) influenced by rooting media and IBA concentration. The results of the present study also revealed the findings of Copes and Mandel, (2000) on Douglas-fir stem cuttings.

Another study by Copper (1935) indicated that 0.02% solution of indole-acetic acid and indole butyric acids and 0.01% solution of naphthyl-acetic acid and naphthyl-acetomide are very effective in inducing root formation on most of citrus varieties.

Lal *et al*. (2009) have also reported increment in percent rooting increment as a result of increase in IBA and NAA concentrations on guava (*Psidium guajava* L.). IBA has been found to be effective in promoting rooting of jackfruit (*Artocarpus heterophyllus Lam.*) stem cuttings (Biswas and Kobayashi, 1995) and increasing percent rooting in pepper (*Piper nigrum L.*) (Irulappan *et al*.,1982).

Badji *et al*. (1991) have observed that treatment with 8% IBA resulted in significantly better rooting (50 - 70%) than did 2%-IBA, 0.2%-NAA and l%-IAA for leafy cuttings collected in the rainy season. The results of the present study also attest the general truth that auxins often hasten root initiation, increase the number and percentage of rooted cuttings as well as quality of roots produced per cutting (Newton *et al*., 1992).

Table 3 Interaction between variety and hormones for percent rooting

Variety	Hormone	Percent rooting
Aba-buna	No hormone	76.85^{c}
Aba-buna	IBA	92.59^{a}
Aba-buna	NAA	82.12^{bc}
Gawe	No hormone	79.18^{c}
Gawe	IBA	94.44^{a}
Gawe	NAA	89.81^{ab}
Melko-CH2	No hormone	80.55^{c}
Melko-CH2	IBA	79.63^{c}
Melko-CH2	NAA	81.48^{c}
LSD (P<5%)		7.998
CV (%)		8.11

Means followed by the same letter(s) are not significantly different (P≤0.05)

4.2 Effect of Rooting Hormone and Leaf Retention on Shoot Parameters

Among shoot parameters, shoot number, shoot height, shoot girth, leaf number, total leaf area, shoot fresh weight and shoot dry weight were considered in this study.

4.2.1 Shoot number

Differences ($P>0.05$) due to both three-way and two-way interactions and the main effects of coffee variety and leaf retention were not significant for shoot number (Appendix Table 3). However, there was a significance difference ($P<0.05$) because of main effect of hormone application (Table 4).

The highest shoot number was observed for IBA (2.11), while NAA and untreated cuttings should significantly lower values in sprouting the new shoots of cuttings. Moreover, its performance of IBA varying by 4 and 7 percent over the mean and hormone untreated cuttings, respectively (Table 4).

The highest number of shoots observed for IBA may also be due to easy translocation of water and mineral nutrients to the above ground parts as a result of enhanced growth roots of cuttings.

The most probable reason for this could be the nature of hormones, as auxins move always from the tip towards the base of shoots, but when applied at the base of cuttings there can be some movement in the opposite direction to develop shoot part as well.

The result of the present study agrees with the work of Kester *et al*. (1990), indicating the role of plant growth substances especially auxin in cell division, multiplication

and specialization in plants. IBA is still probably the best hormone for general use, because of its nature, which non-toxic to plants over a wide range of concentrations levels (Blazich, 1988 and Kester *et al*., 1990).

4.2.2 Shoot girth

The ANOVA table for shoot girth indicates that there were no significant differences ($P>0.05$) for both three-way and two-way interactions, and for the main effect of coffee variety (Appendix Table 4). However, there were significant ($P<0.05$) difference between rooting hormones and leaf retention treatment for shoot girth (Table 4; Table 5).

Accordingly, the highest value for shoot girth was obtained from IBA treated plots (3.38mm) which, however, was statistically at par with NAA (3.15mm) at $P<0.05$. IBA was varying by 6 and 10 percent advantage over the mean and hormone untreated cuttings respectively, where as the performance of NAA was less than the mean but greater than hormone untreated cuttings (Table 4)

With regard to leaf retention, cuttings which were with a pair of leaves by the time of sticking exhibited significantly higher shoot girth (3.32mm) than did cuttings which retained single leaf (3.06mm) (Table 5).

The variability among cuttings in terms of their shoot girth could be attributed to the physiological condition of the cuttings. This might include differences in the concentration of endogenic shoot promoters and the reserve food material within the cuttings especially in the leaves. This result agreed with earlier observations in Madagascar (Coste, 1992) and Nigeria (Adeyemi *et al*., 2007) on sprouting and rooting of *Coffea canephora* stem cuttings whose leafiness was found to be a critical factor.

4.2.3 Leaf number

As shown in Appendix Table 5, analysis of variance for mean leaf number of cuttings indicates that there were no significant differences ($P>0.05$) for both three-way and two-way interactions and for the main effect of coffee variety. However, there was significance ($P<0.05$) difference for the main effects of rooting hormones and leaf retention treatments (Table 4 and Table 5).

The highest number of newly developed leaves was observed for IBA (10.76), whereas the least value was observed for cuttings treated with NAA (9.22) (Table 4). However, both IBA and NAA treatments were not statistically different ($P<0.05$) from the control plot maintained with no hormone (9.94) (Table 6). In comparison, it was observed that IBA was superior by 7.92 and 8.25 percent over the mean and the control, respectively.

With regard to leaf retention, cuttings having a pair of leaves by the time of sticking significantly developed more number of leaves (10.53) than did cuttings which initially had single leaf (9.42). The performances of cuttings with a pair of leaves in terms of new leaf development was much better (5.62%) than the mean value (Table 5). This could probably be due to the vital function of leaf as a site for the manufacture of food and other plant physiological processes, such as respiration, contributing for the development of leaf buds.

Results of the present investigation were in agreement with an earlier observation reported in Nigeria (Adeyemi *et al*. 2007) indicating that leafiness is a critical factor in the sprouting and rooting of *Coffea canephora* stem cuttings. Similarly it has been reported that *Coffea canephora* stem cuttings without leaf showed zero percents of sprouting and rooting, in Madagascar (Coste, 1992)

4.2.4 Total leaf area

The three-way interaction, the two-way interaction and the main effects of coffee variety and leaf retention were not significant (P> 0.05) for mean total leaf area of cuttings. However, the effect of rooting hormones was observed to be quite significant (Appendix Table 6).

Significantly (P<0.05) the higher mean total leaf area (58.52 cm^2) was observed for cuttings treated with IBA followed by NAA (48.17cm^2), whereas the minimum value (47.24 cm^2) was recorded for hormone untreated cuttings (Table 4). The performance of IBA was superior over the mean and hormone untreated cuttings by 14 and 24 percent, respectively.

The most probable reason for the increment in total leaf area of hormone treated cuttings was the ability of the rooting hormones to be translocated to the shoot part to develop new leaves even though they were applied to the basal portion of the stem cuttings.

Table 4 Effect of rooting hormone on mean shoot number, shoot girth, leaf number and total leaf area of cuttings

Variety	Shoot number	Shoot girth(mm)	Leaf number	Total leaf area(cm^2)
No hormone	1.98[b]	3.06[b]	9.94[ab]	47.24[b]
IBA	2.11[a]	3.38[a]	10.76[a]	58.52[a]
NAA	2.00[b]	3.15[a]	9.22[b]	48.17[b]
Mean	2.03	3.19	9.97	51.32
LSD (5%)	0.098	0.257	0.866	6.409
CV (%)	7.11	11.84	12.83	18.43

Means followed by the same letter are not significantly different (P≤0.05)

Table 5 Effect of leaf retention on mean shoot girth (mm) and leaf number of cuttings

Leaf retention	Shoot girth(mm)	Leaf number
One leaf	3.06[b]	9.42[b]
Two leaves	3.32[a]	10.53[a]
Mean	3.19	9.97
LSD(5%)	0.209	0.707
CV (%)	11.84	12.83

Means followed by the same letter are not significantly different (P≤0.05)

4.2.5 Shoot height

As presented in Appendix Table 7, analysis of variance for mean shoot height indicates that there was no significant difference (P<0.05) for both three-way and two-way interactions and for the main effects of rooting hormones and leaf retention. However, there was a significance (P<0.05) difference between coffee varieties for mean height of newly grown shoots of cuttings (Table 6).

Accordingly, significantly the higher value was observed for Aba-buna (6.90cm) followed by Melko-CH2 (5.72cm) which however was statistically similar with Gawe (5.24cm) (Table 8). Variety Aba-buna had taller shoot as compared to the other two varieties and it was superior by 16, 32 and 21 percent over the mean, Gawe and Melko-CH2, respectively. This is probably due to the genetic potential of the variety that favored shoot growth and stem elongation through their response differently based on the environment of the nursery (Media light etc...) (Braun *et al.*, 2007).

The result of the present investigation is in agreement with the findings of Mawardi and Purwadi (2004) who reported that, success of propagation of Robusta coffee clones by cuttings was significantly affected by genetic factor, especially on the

characteristics of percentage of rooted cuttings, total root length and number of root and shoots growth.

Similarly, Fahl and Carelli (1994) have, evaluated the growth (foliar area and height) of several cultivars of *Coffea arabica* and *Coffea canephora* in the nursery and concluded that various cultivars studied responded differently based on the environment of the nursery. Braun (2007), has also reported similar findings on the growth of stem shoots of Robusta coffee variety Conilon.

Even though, the data was calculated based on the mean value for each hybrid coffee variety, the tallest (17.5 cm) shoot (sucker) was observed for Aba-buna cuttings.

Table 6 Mean height of newly grown shoots of stem as affected by coffee variety

Variety	Shoot height(cm)
Aba-buna	6.90[a]
Gawe	5.24[b]
Melko-CH2	5.72[b]
Mean	5.95
LSD (5%)	0.757
CV (%)	18.76

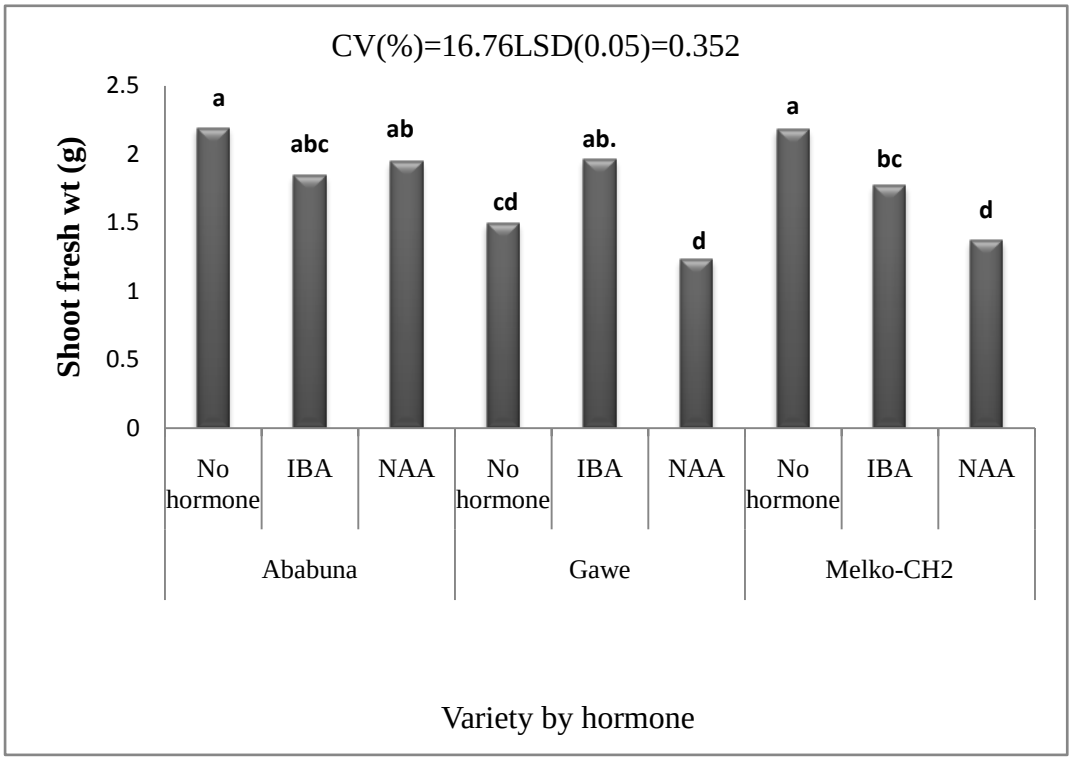
Means followed by the same letter are not significantly different (P≤0.05)

4.2.6 Shoot fresh weight

The three-way interaction and two-way interaction of leaf retention by rooting hormones were not significant (P> 0.05) for shoot fresh weight of cuttings. However, the interaction between hybrid coffee varieties and leaf retention and that of variety and rooting hormones were significant (Appendix Table 8)

Significantly the highest shoot fresh weight (2.19 g) was observed for Aba-buna followed by Melko-CH2 (2.18g) under hormones untreated condition. However, they were statistically at par (P> 0.05) with Aba-buna treated with both hormones and Gawe treated with IBA while the lowest shoot fresh weight was observed for Gawe and Melko-CH2 treated with NAA, statistically at par with hormone untreated Gawe.

The performances of Aba-buna and Melko-CH2 with no hormone were higher by 78 percent over the least value observed for NAA treated Gawe (Figure 1). Except for variety Gawe whose response was better with IBA treatment as compared to other varieties, application of rooting hormones on Aba-buna and Melko-CH2 did not affect shoot fresh weight. This could probably be due to the translocation of more auxins to the root part than to the shoot system of the latter varieties.



Bars capped with the same letter(s) are not significantly different at (P≤0.05)

Figure 1 Effects of rooting hormones on shoot fresh weight of coffee varieties.

The interaction between of coffee variety and leaf retention was also significant and, the highest shoot fresh weight was observed for cuttings of Aba-buna having pair of leaves, followed by Gawe (Table 7), which was statistically at par with Melko-CH2 with a pair of leaves and Melko-CH2 and Aba-buna with single leaf, while the lowest was observed from cuttings of Gawe with single leaf retention. The performance Shoot fresh of Aba-buna with a pair of leaves excelled the value observed for Gawe by 76 percent.

The most probable reason for the observed shoot fresh weight is due to better performance of root length and root number of the variety.

Table 7 Effects of leaf retention on shoot fresh weight of stem cuttings of hybrid coffee varieties

Variety	Leaf retention	Shoot fresh weight (g)
Aba-buna	One leaf	1.79[b]
Aba-buna	Two leaves	2.20[a]
Gawe	One leaf	1.25[c]
Gawe	Two leaves	1.86[b]
Melko-CH2	One leaf	1.82[b]
Melko-CH2	Two leaves	1.72[b]
LSD (5%)		0.287
CV (%)		16.76

Means followed by the same letter are not significantly different (P≤0.05)

4.2.7 Shoot dry weight

As presented in Appendix Table 9 and Figure 2, analysis of variance for shoot dry weight of cutting indicates that the three-way interaction and leaf retention by rooting

hormone were not significant (P > 0.05). However, the interaction between either coffee variety and rooting hormone or variety and leaf retention was observed to be significant.

The highest shoot dry weight was observed for Melko-CH2, followed by Gawe treated with no hormones (Table 8), while the lowest value was recorded for Gawe treated with NAA being statistically at par with Melko-CH2 treated with NAA. On the other hand, Melko-CH2 which exhibited the highest value was statistically similar ($p<0.05$) with Aba-buna treated with different level of hormones, Gawe treated with no hormones, and with IBA and Melko-CH2 treated with IBA.

Table 8 Effect of rooting hormones on mean shoot dry weight of hybrids coffee varieties

Variety	Hormones	Shoot dry weight (g)
Aba-buna	No hormone	0.635[a]
Aba-buna	IBA	0.621[a]
Aba-buna	NAA	0.604[a]
Gawe	No hormone	0.664[a]
Gawe	IBA	0.614[a]
Gawe	NAA	0.402[c]
Melko-CH2	No hormone	0.679[a]
Melko-CH2	IBA	0.587[ab]
Melko-CH2	NAA	0.477[bc]
LSD (5%)		0.111
CV (%)		16.41

Means followed by the same letter(s) are not significantly different (P≤0.05)

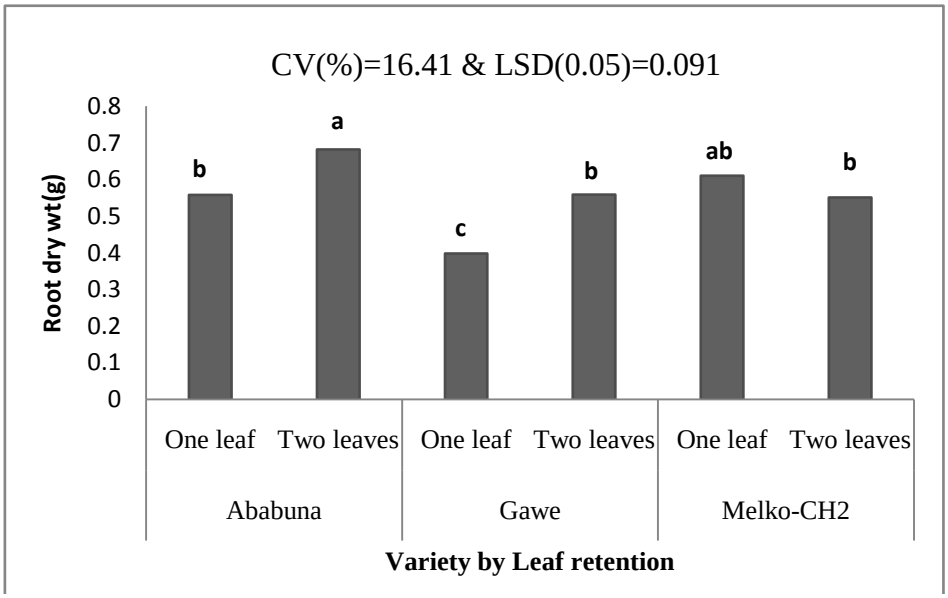
An increase in shoot height of Melko-CH2 and Aba-buna without rooting hormones over the least value recorded for Gawe was about by percent. Therefore, application

of rooting hormones didn't improve shoot dry weight in all varieties. In principle, rooting hormones like IBA and NAA do promote root initiation and development but their subsequent effect on shoot and root growth is modified by the type of media and the nutritional status of it. Therefore, the observed differences are more of genetic, although modified by the effect of rooting hormones.

The interaction of hybrid coffee variety by leaf retention was highly significant for shoot dry weight. Accordingly Aba-buna having a pair of leaves followed by Melko-CH2 with single leaf retention, exhibited the highest shoot dry weight whereas the least was observed for Gawe cuttings having a single leaf attached with(Figure 2).

Semi-hardwood cuttings of Melko-CH2 and Gawe with a pair of leaves had similar shoot dry weight as did Aba-buna having single leaf retention and Gawe having a pair of leaves attached with. Similarly, Aba-buna with a pair of leaves and Melko-CH2 with single leaf were not statistically different at $p<0.05$. Leaf retention resulted in no significant effect on shoot dry weight of Melko-CH2 (Figure 2). Among the treatment combinations, Aba-buna and Melko-CH2 cuttings having pair of leaves produced about 71% and 52% more shoot dry weight over the least value recorded for Gawe cuttings with single leaf retention, respectively.

The most probable reason for the observed shoot dry weight for those hybrid coffee variety was due to better performance in increasing leaf number, leaf area and shoot fresh weight.



Bars capped with the same letter(s) are not significantly different at (P≤0.05)

Figure 2 Effect of leaf retention on mean shoot dry weight of cuttings of hybrid coffee varieties.

4.3 Effect of Rooting Hormone and Leaf Retention on Root Parameters

Among root parameters, root volume, root girth, root length, root number, root dry weight and root fresh weight, were considered in this study. However, variables evaluating both shoot and root (root to shoot ratio and total dry matter) were also included.

4.3.1 Root volume

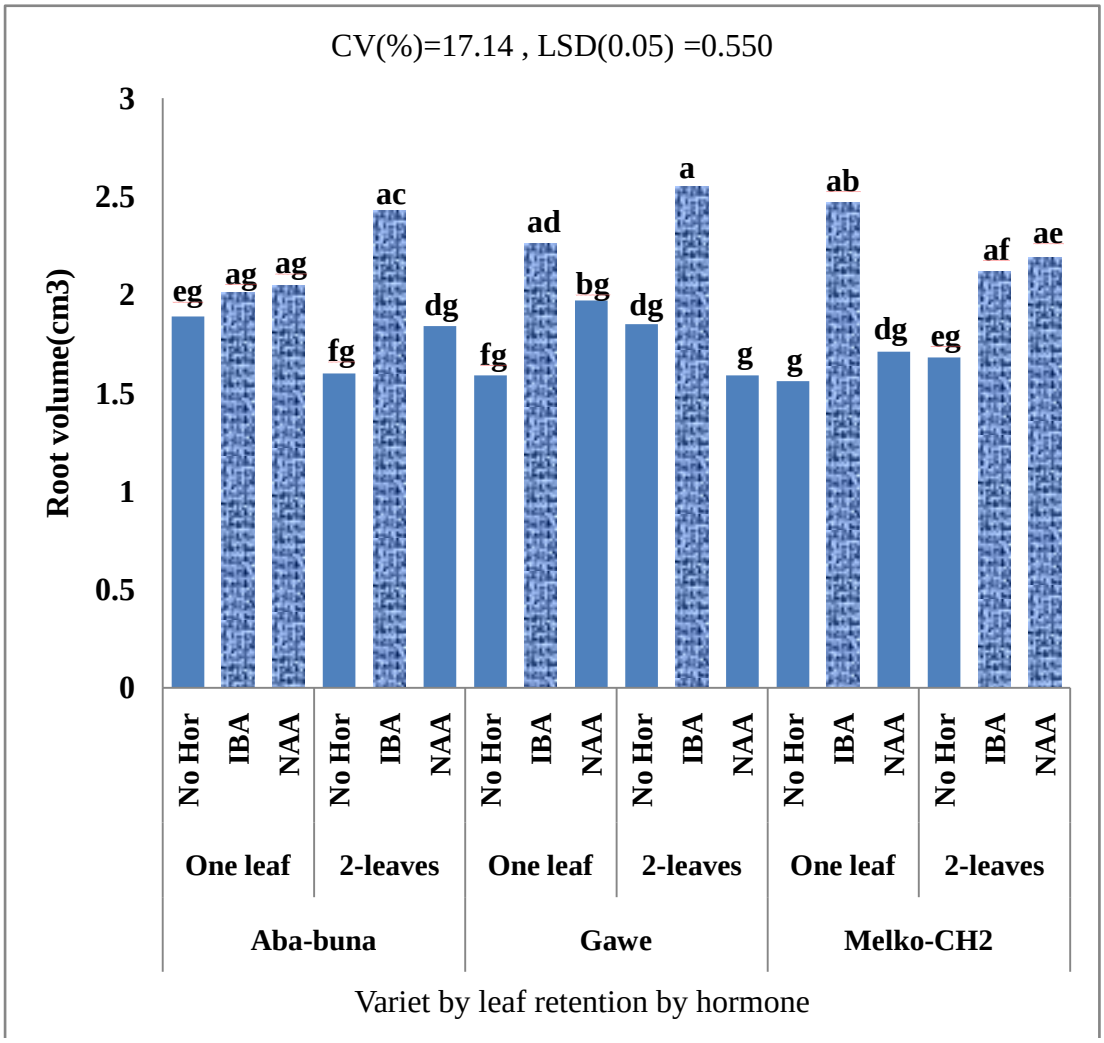
Analysis of variance for root volume stem cuttings indicates that the three way interaction was significant (P≤ 0.05) (Appendix Table10). Significantly the highest root volume was observed for Gawe (2.55 cm^3) cuttings having a pair of leaves, attached with followed by Melko-CH2 (2.47cm^3) with single leaf, both treated with

IBA. However, it was statistically similar ($P<0.05$) with the values recorded for cuttings of Aba-buna treated with both hormones and with single leaf and treated with IBA for pair of leaves, Gawe treated with IBA for single leaf, and for Melko-CH2 treated with both hormones having pair of leaves.

The minimum root volume was observed for single leafed cuttings of Melko-CH2 treated with no hormone and cuttings of Gawe with a pair of leaves and treated with NAA, which, however, was statistically similar ($P<0.05$) with all treatment combinations, except for these that showed significantly higher values (Figure 3). It was observed that the combination of IBA with other treatments produced better root volume than did NAA. However, NAA was found to be better and effective only when used to treat cuttings of Aba-buna having single leaf retention and Melko-CH2 with a pair of leaves.

The most probable reason for the observed root volume for variety Gawe was due to better performance in rooting and root number as compared to other coffee varieties.

The result of the present investigation is in agreement with the work done by Heinz *et al.* (1962), indicating that exogenous IBA serves as a source for free IBA, and the difference between the varieties is a consequence of the free IBA which is released, transported and accumulated in the site of root formation.



Bars capped with the same letter(s) are not significantly different at (P≤0.05)

Figure 3 Effects of leaf retention and hormones on root volume (cm^3) of hybrid . coffee cuttings.

4.3.2 Root number of stem cuttings

As presented in Appendix Table 11, analysis of variance for mean of root number of cutting indicates that three-way interaction, the two-way interactions of rooting hormones with coffee varieties and leaf retention the two-way interactions except variety by leaf retention, and the main effect of variety were not significant (P> 0.05). However, there was a significant interaction between leaf retention and coffee

varieties (P< 0.05) and very highly significant (p<0.0001) of rooting hormones on mean number of roots per cutting.

Accordingly, the maximum number of roots was counted for Gawe with a pair of leaves, followed by Melko-CH2 with similar leaf retention, which, however, was statistically at par (P<0.05) with Melko-CH2, Gawe, and Aba-buna with single leaf retentions and Aba-buna with a pair of leaves, whereas, the lowest value was recorded for Gawe, having single leaf retention (Table 9; Plate 10). Gawe with a pair of leaves was superior by 22 percent over the mean in terms of root number per cutting. This is probably due to the combined effect of inherent characteristics of hybrids and leaf retention.

Table 9 Effects of leaf retention on mean root number of cuttings hybrid coffee varieties

Variety	Leaf retention	Root number
Aba-buna	One leaf	3.74[b]
Aba-buna	Two leaves	3.73[b]
Gawe	One leaf	3.44[b]
Gawe	Two leaves	4.67[a]
Melko-CH2	One leaf	3.63[b]
Melko-CH2	Two leaves	3.76[b]
LSD (5%)		0.542
CV (%)		14.77

Means followed by the same letter are not significantly different (P≤0.05)

With regard to the effect of rooting hormones, significantly higher root number was observed for IBA (4.36) followed by NAA (3.84) while the minimum (3.23) was recorded for untreated cuttings (Table 10).

The performance of IBA was much better than NAA in increasing root number of the cuttings and it was varying by 14 percent over the mean and 33 per cent over no hormone. This may be attributed to enhanced tissue sensitivity and increased rooting via increased internal free IBA resulting in increased number of roots (Oloyede *et al*., 2004). This indicates that the use of rooting hormones is a necessary practice towards increasing the root number of stem cuttings in vegetative propagation process.

The result of the present study was in line with the work of Carvalho *et al*. (1995), indicating that translocation of carbohydrates from the leaves plays important role in root development. Similarly, these results are in agreement with the findings of Chalapathi *et al.* (1999) and Lal *et al*. (2009) who have reported that, the number and length of roots increase as a the result of increase in IBA and NAA concentrations in guava (*Psidium guajava* L.), however, IBA was best. In another study, Hartmann *et al*. (2002), have observed that increased number of roots due to auxin application and they have concluded that, this is a common feature in many perennial crops. However, as observation on the present study, IBA seems the best hormone for initiation and growth of roots in the stem cuttings of woody species.

4.3.3 Root length of stem cuttings

Analysis of variance for mean root length indicates that, the three-way interaction, all two-way interactions and the main effect for leaf retention were not significant ($P>0.05$). However, there were a very highly significant ($P\leq0.001$) difference between the main effects of rooting hormones and significance ($P\leq0.05$) difference between hybrid varieties, respectively for shoot length (Appendix Table 12).

The highest mean root length was observed for cuttings treated with IBA (10.66 cm) followed by NAA (10.24cm). However, these values were not statistically different at $P<0.0001$, whereas the lowest value was recorded for hormone untreated (8.45 cm) cuttings (Table 10, Plate 11 and Plate 12).

The length of the primary root varied from the mean by 9 and 5 percent for IBA and NAA treated cuttings respectively. An increase in length of the roots might be probably due to an early initiation of roots at higher concentrations of IBA and more utilization of the food materials due to early formation of the roots.

On the other hand, it was observed that significantly ($p< 0.05$) longer roots were produced by Aba-buna cuttings (10.18cm), followed by Melko-CH2 (9.66cm), which was not statistically different from Gawe (9.52cm) (Table 11). This is probably due to the inherent genetic characteristics of variety Aba-buna which favored the cuttings to have longer roots as compared to those of Gawe and Melko-CH2.

The result of the present study substantiates the findings of Oloyede *et al*. (2004), who have evaluated the effect of rooting medium, hormonal treatment and use of half node on the vegetative propagation of *Coffea canephora Pierre ex. Froehner*. Their finding indicated that IBA treatment had a significant influence on the root length.

Similar trend has been reported by Chalapathi *et al.* (2001) and Debnath (2008) in stevia. In another study conducted by Singh *et al.* (2003), the increase in root length has been also attributed to the action of auxin and its activity which might have caused hydrolysis and translocation of carbohydrates and nitrogenous substances at the base of cuttings and resulted in accelerated cell elongation and cell division in suitable environment.

Lal *et al.* (2009), have also reported that, the number and length of roots increase as a result of IBA and NAA concentrations on guava (*Psidium guajava l.*). Similar result has been reported by Omolaja and Obatolu (1999).

With regard to the response of varieties, the result agrees with the work of Mawardi and Purwadi (2004), indicating that success of propagation with cuttings was significantly affected by genetic factor (clone), especially on the characteristics of percentage of rooted cuttings, total root length and number of roots.

4.3.4 Root girth of stem cuttings

As shown in the Appendix Table 13, analysis of variance for root girth indicates that there was no significant difference ($P>0.05$) for both three-way and two-way interactions. However, there were a very highly significant ($P<0.0001$) difference for rooting hormone and significant ($P<0.05$) difference for leaf retention and coffee variety as main effects.

The highest root girth was observed for IBA (2.77mm) followed by NAA (2.66mm), whereas the least value was observed for hormone untreated cuttings. Both rooting hormones were not statistically different ($p<0.0001$) and performed better than untreated cuttings. IBA was superior by 9 and 26 percent over the mean and no hormone, while NAA was superior by 5 and 21 percent over the mean and no hormone, respectively (Table 10).

This is probably due to the activity of plant growth substances especially auxin, controlling the production of adventitious roots in plants through cell division, multiplication and specialization (Newton *et al*., 1992).

Table 10 Effect of rooting hormones on root number root length and root girth of stem cuttings

Hormones	Root number	Root length (cm)	Root girth (mm)
No hormone	3.28[c]	8.45[b]	2.19[b]
IBA	4.36[a]	10.66[a]	2.77[a]
NAA	3.84[b]	10.24[a]	2.66[a]
Mean	3.83	9.78	2.54
CV (%)	14.77	7.54	11.68
LSD(P <0.0001)	0.383	0.499	0.201

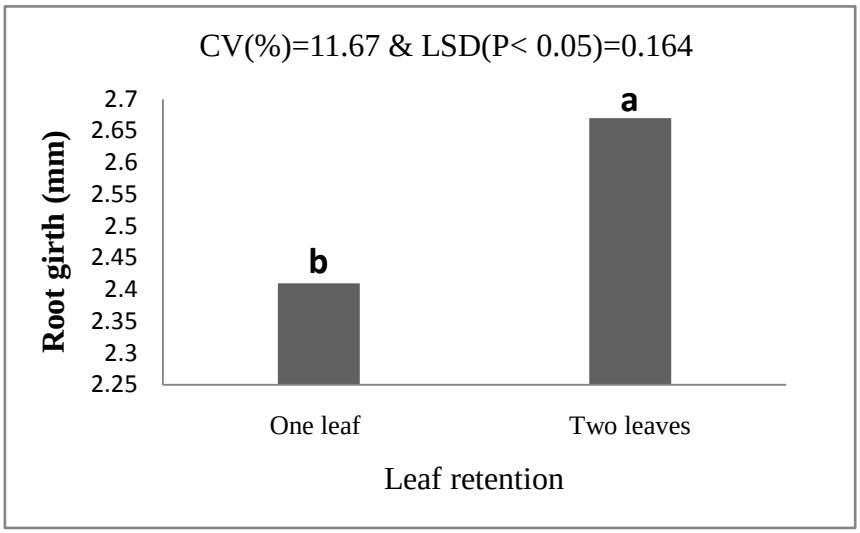
Means followed by the same letter are not significantly different (P≤0.05)

With regard to leaf retention, cuttings having a pair of leaves by the time of sticking had the highest root girth than did cuttings which retained a single leaf (Figure 4). Cuttings with a pair of leaves were varying by 5 percent over the mean and those with single leaf retention were lower than the mean by 5 percent. This is probably due to the presence of more leaf area that hastens rate of photosynthesis area for growth and metabolic activity.

There was a significant different between coffee varieties for root girth and of Aba-buna was observed to be better than Gawe and Melko-CH2.The highest value was recorded for Aba-buna (2.73mm) followed by Gawe (2.48mm) (Table 11). However, there was no statistical difference (P>0.05) between Gawe and Melko-CH2, as the lowest value was recorded for melko-CH2 (2.41mm). Aba-buna was varying by 8 percent over the mean value, while Gawe and Melko-CH2 exhibited lower vale than the mean (Table 11).

This may be due to the genetic potential of the variety favouring root growth of the stem cuttings.

The present study is in agreement with the work done by Rathore (1984), who reported that the increase in length and diameter of root may be due to successful rooting of IBA treated cuttings. Similar findings have also been reported for Kiwifruits (*Actinidia deliciosa*) by Panwar *et al*., (2001).



Bars capped with the same letter are not significantly different at (P≤0.05)

Figure 4 Effect of leaf retention on mean root girth of coffee stem cuttings.

Table 11 Variation between hybrid coffee variety as for root length and root girth of stem cuttings

Variety	Root length(cm)	Root girth(mm)
Aba-buna	10.18[a]	2.73[a]
Gawe	9.52[b]	2.48[b]
Melko-CH2	9.66[b]	2.41[b]
Mean	9.78	2.54
LSD(5%)	0.499	0.201
CV (%)	7.54	11.68

Means followed by the same letter(s)are not significantly different (P≤0.05)

4.3.5 Root fresh weight

As presented in Appendix Table 14, analysis of variance for root fresh weight indicates that the three way interaction of factors was significant at P≤0.05, where the highest values were observed for IBA treated cuttings of Gawe (2.75 g) and Aba-buna (2.71g) with a pair of leaves. However, it was not statistically different (P≤0.05) from Gawe and Melko-CH2 with single leaf and treated with IBA, and Melko-CH2 with a pair of leaves treated with both hormones. The lowest value was recorded for single leaf cuttings of Gawe (1.21 g) treated with NAA, which was statistically at par (P > 0.05) with Aba-buna, Gawe and Melko-CH2 with single leaf retention and treated with no hormone, and Aba-buna and Melko-CH2 with single leaf retention and treated with IBA and NAA, respectively.

The performance of IBA was better than that of NAA in all combinations except for Aba-buna cuttings with single leaf retention (Table 12). On the other hand, the superiority of Gawe for root fresh weight was varying by 56 percent, while Aba-buna was varying by 55 percent over the least value recorded for Gawe stem cuttings, respectively.

The most probable reason for the observed root fresh weight for those hybrid varieties was probably due to the success in rooting performance, better root length and number.

It seems that fresh weight of roots was related to their number and length of roots. The present study is in agreement with the observation made by Farooqi *et al.* (1994), in *Rosa damascene,* indicating that an increase in number and length of roots have directly influened the fresh weight of roots.

Table 12 Effect of hybrids, leaf retention and rooting hormones on mean root fresh weight of cuttings of hybrid coffee varieties

Variety	Leaf retention	Hormone	Root fresh weight (g)
Aba-buna	One leaf	No hormone	1.57^{def}
Aba-buna	One leaf	IBA	1.91^{def}
Aba-buna	One leaf	NAA	2.10^{cd}
Aba-buna	Two leaves	No hormone	1.91^{cde}
Aba-buna	Two leaves	IBA	2.71^{ab}
Aba-buna	Two leaves	NAA	1.99^{cde}
Gawe	One leaf	No hormone	1.22^{f}
Gawe	One leaf	IBA	2.21^{abc}
Gawe	One leaf	NAA	1.21^{f}
Gawe	Two leaves	No hormone	2.00^{cde}
Gawe	Two leaves	IBA	2.75^{a}
Gawe	Two leaves	NAA	1.82^{cde}
Melko-CH2	One leaf	No hormone	1.22^{f}
Melko-CH2	One leaf	IBA	2.24^{abc}
Melko-CH2	One leaf	NAA	1..50^{ef}
Melko-CH2	Two leaves	No hormone	2.19^{bc}
Melko-CH2	Two leaves	IBA	2.27^{abc}
Melko-CH2	Two leaves	NAA	2.30^{abc}
LSD (P<5%)			0.550
CV (%)			17.07

Means followed by the same letter(s) are not significantly different (P≤0.05)

4.3.6 Root dry weight

Analysis of variance for root dry weight of cuttings indicates that the three-way interaction and the two-way interaction of leaf retention with rooting hormone were

not significant (P > 0.05). However, there was a significant interaction between hybrid coffee varieties and leaf retention or hybrid varieties and rooting hormone (Appendix Table15).

The highest mean root dry weight was observed for Aba-buna (0.392g) followed by Gawe (0.379g), both of them treated with IBA. However, it was not statistically different (P<0.05) from Aba-buna treated with NAA (0.362g) or with no hormone (0.343)(Figure 5), whereas the lowest value was observed for Gawe treated with NAA (0.248g) which was statistically at par with Gawe, treated with no hormone (0.312g) and Melko-CH2 treated with IBA (0.288g) or with NAA ((0.265g).The performances of Aba-buna and Gawe in combination with IBA were better than Melko-CH2 treated with the same hormone.

Similarly, significantly higher root dry weight was observed for Aba-buna (0.409g) and Gawe (0.403g) with a pair of leaves (Table 13). However, both of them were not statistically different (P<0.05), whereas, the lowest values were recorded for Gawe (0.222g) and Melko-CH2 (0.241) with single leaf retention. Aba-buna with single leaf was not statistically different (P>0.05) from Melko-CH2 having a pair of leaves.

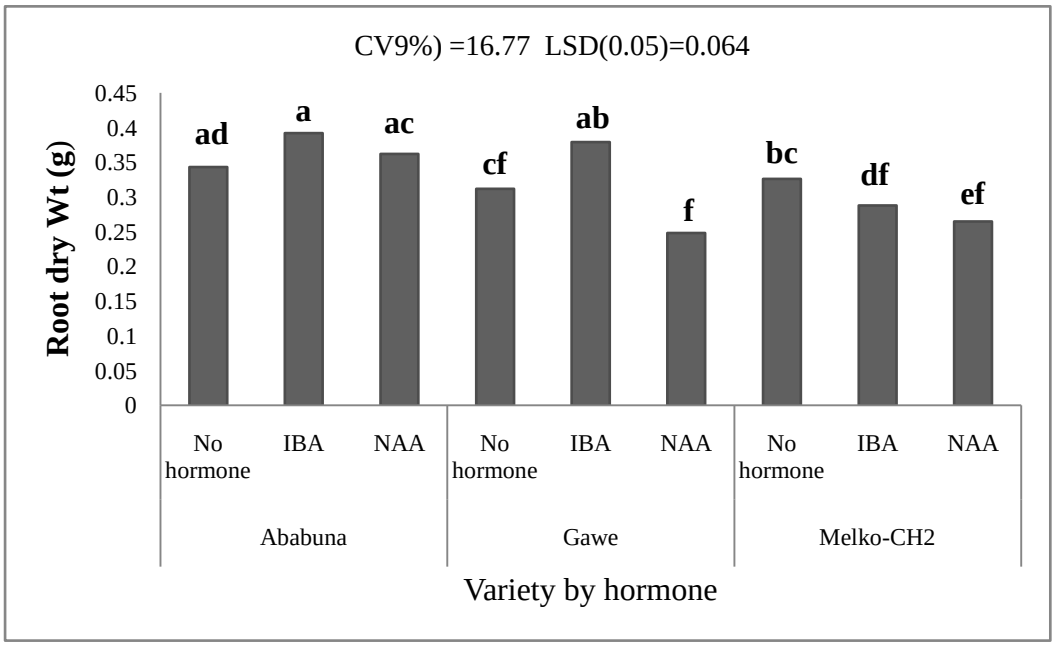
Aba-buna and Gawe cuttings with a pair of leaves had more root dry weight than did Melko-CH2 with both type of leaf retention, and they out yielded the least value (Gawe with single leaf retention) by 84 and 82 percent, respectively.

The most probable reason for the observed root dry weight was a well-branched root system, even at the expense of shoot growth, is the secret of success in nursery work. In other words: the root: shoot ratio should be high-much root growth in relation to the size of the shoot.

Dry weight refers to the amount of carbon atom photo-assimilated and translocated to root/shoot; which remains in the dried root/shoot after complete removal of the water or moisture (Burdett, 1990).

The results of the present study agree with the work of Nelson (2004) who has reported that cuttings of different plant species showed genotype dependent rooting and increment in root growth and weight.

Consistent with this finding, the observations of Govinden-Soulange *et al*. (2009) on *Hibiscus sabdariffa* have shown that IBA treatment resulted in the highest dry matter accumulation in the roots was IBA for softwood and semi hardwood cuttings, although the effect of various co-factors including endogenous auxins on rooting has been reported to be species dependent (Bertram, 1991).



Bars capped with the same letter(s) are not significantly different at (P≤0.05)

Figure 5 Effect of rooting hormones on mean root dry weight of stem cuttings of hybrid coffee varieties.

Table 13 Effect of leaf retention on mean root dry weight of stem cuttings of hybrid coffee varieties

Variety	Leaf retention	Root dry weight(g)
Aba-buna	One leaf	0.322 [b]
Aba-buna	Two leaves	0.409 [a]
Gawe	One leaf	0.222 [c]
Gawe	Two leaves	0.403 [a]
Melko-CH2	One leaf	0.241 [c]
Melko-CH2	Two leaves	0.346 [b]
LSD (5%)		16.77
CV (%)		0.052

Means followed by the same letter(s) are not significantly different (P≤0.05)

4.4 Dry Matter Production and Partitioning

The results of root to shoot ratio and total dry weight were given as follows:-

4.4.1 Root to shoot ratio

The three-way, two-way interactions and the main effect of hormones were not significant (P> 0.05) for root to shoot ratio of the cuttings. However, leaf retention treatments and hybrid coffee varieties should significant differences for root to shoot ratio (Appendix Table16).

The highest value was observed for cuttings with a pair of leaf (0.65), whereas cuttings with single leaf had the lowest value (0.52) (Figure 6).

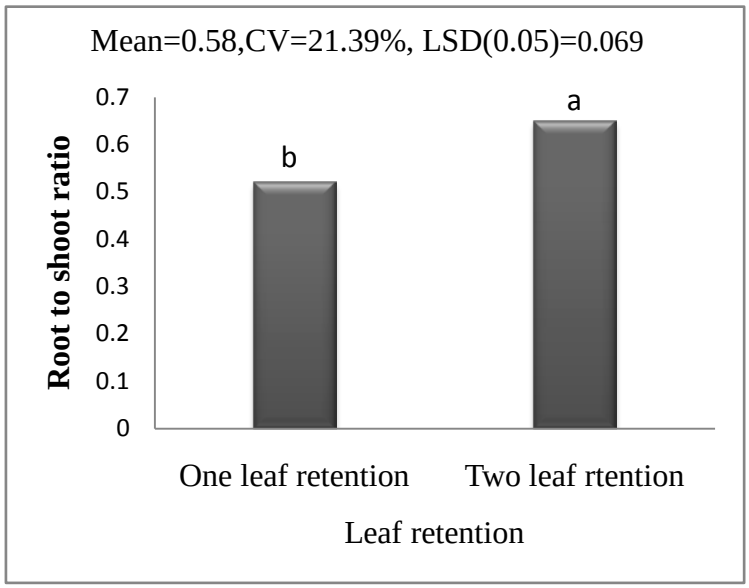
The increase in root to shoot ratio of cuttings with a pair of leaves (25 percent over single leafed cuttings) could be probably due to maintenance of more leaf area for photosynthesis and then, more dry matter accumulation and partitioning to the root system of coffee cuttings (Tesfaye, 1995).

With regard to hybrid coffee varieties, the highest root to shoot ratio (0.63) was observed for Gawe cuttings, which, however, was statistically at par with Aba-buna (0.59), while the lowest value (0.52) was registered for cuttings of Melko-CH2, being statistically at par with Aba-buna (Table 14). The performance of Gawe was varying by 9 percent over the mean.

This is probably due to the inherent genetic characteristics and potential of the variety. In other words: the root: shoot ratio should be high-much root growth in relation to the size of the shoot.

The result of the present investigation is in agreement with the work done by Burdett, (1990) that the ratio of root dry mass, or root to shoot ratio, is used to evaluate the drought avoidance potential of container stock plant. Moreover, roots allow a plant to absorb water and nutrients from the surrounding soil, and a healthy root system is key to a healthy plant. The root: shoot ratio is one measure to help in assessing the overall health of plants (Wood and Roper, 2000).

The survival and uniformity of the plants in the field depends on their roots rather than the shoots. Unfortunately the roots grow in the dark, the shoots in the light and it is very common in nursery work to pay more attention to the shoots than to the roots. A small plant with relatively many roots is much better equipped to survive field planting than a large plant with a small proportion of roots (Verheij, 2004).



Means followed by the same letter are not significantly different (P≤0.05)

Figure 6 Effect of leaf retention on root to shoot ratio of coffee stem cuttings.

Table 14 Variations among hybrid coffee varieties for root to shoot ratio of stem cuttings

Variety	Root to shoot ratio
Aba-buna	0.59[ab]
Gawe	0.63[a]
Melko-CH2	0.52[b]
Mean	0.58
LSD (P <0.0001)	0.085
CV (%)	21.39

Means followed by the same letter(s) are not significantly different (P≤0.05)

4.4.2 Total dry weight

The three-way interaction and the two-way interaction of leaf retention by rooting hormone were not significant (P>0.05) for total dry weight of cuttings. However, total dry matter yield of the cuttings was significantly affected by the interactions between hybrid coffee varieties and leaf retention and between varieties and rooting hormones (Appendix Table 17).

Significantly the highest value (1.09g) was observed for Aba-buna treated with IBA and Melko-CH2 treated with no hormone. However, both of them were statistically at par (P<0.05) with Aba-buna treated with NAA or with no hormone each (0.97g) and Gawe treated with IBA (0.99g), Whereas the lowest value was observed for Gawe treated with NAA (0.56g), which was statistically similar with the values recorded for Melko-CH2 treated with NAA(0.74) (Figure 7).

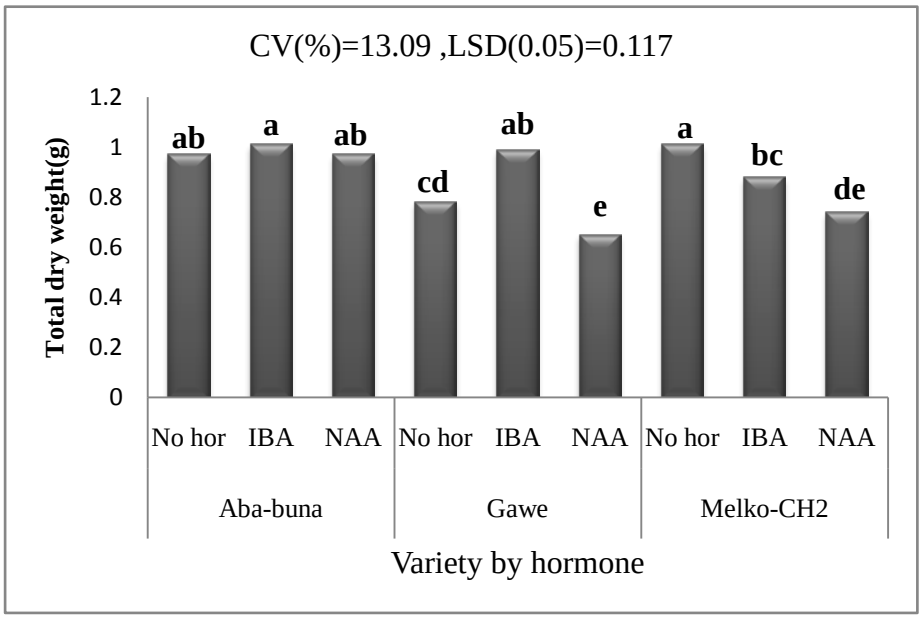
The performances of Aba-buna in combination with IBA and Melko-CH2 with no hormone were better than other combinations. However, application of rooting hormones did not significantly increase total dry weight of Aba-buna and Melko-CH2 cuttings, except for Gawe variety. This could be probably due to variations in varietal response to auxins.

With regard to interaction of hybrid variety by leaf retention for total dry weight, the highest value was observed for Ababuna (1.09g), followed by Gawe (0.99g) both having a pair of leaves, while the lowest value was recorded for cuttings of Gawe (0.85g) having single leaf retention (Table 15).This could be probably due to the combination of the inherent characteristics of the variety with leaf retention for dry matter production and accumulation. Variety Ababuna with pair of leaf retention out yielded Gawe and Melko-CH2 of the same type of leaf retention by 20 and 22

percent, respectively. This indicated that the dry matter accumulation and partitioning, and some physiological responses of coffee were affected differently by the inherent characteristics of the variety.

The results were in agreement with the findings of Braun (2007), who verified in *Coffea canephora* that the effect of cutting type was significant for root length and total dry matter yield. Similarly, it has been observed that semi-woody cutting with the longest root had the highest average total dry weight (Rezende *et al*., 2010).

The results of the present study agree with the work of Govinden-Soulange *et al*. (2009), indicating that auxin treatment was seen to have a significant effect on dry matter accumulation depending on the type of cutting used, and that, dry weight of cuttings increased significantly in both softwood and semi hardwood cuttings treated with IBA.



Bars capped with the same letter(s) are not significantly different at (P≤0.05)

***Key**: No hor = No Hormone*

Figure 7 Effect of rooting hormones on total dry weight of cuttings of hybrid coffee varieties.

The increase in total dry weight of cuttings with two leaves could be attributed to the enhanced rate of photosynthesis because of greater leaf area and accumulation of more dry matter in plant parts (Tesfaye, 2005).

Table 15 Effect of leaf retention on total dry weight of stem cuttings of hybrid coffee varieties

Variety	Leaf retention	Total dry weight(g)	Variety mean
Aba-buna	One leaf	0.88[c]	
Aba-buna	Two leaves	1.09[a]	0.985
Gawe	One leaf	0.62[d]	
Gawe	Two leaves	0.99[b]	0.805
Melko-CH2	One leaf	0.85[c]	
Melko-CH2	Two leaves	0.89[c]	0.870
LSD(P<5%)		0.096	
CV(%)		13.09	

Means followed by with the same letter are not significantly different (P≤0.05)

4.5 Correlation Analysis among Shoots and Root Variables

Correlation studies showed that most of the growth parameters were positive, moderate and significantly ($P \leq 0.05$) correlated among each other and negative correlation was not observed even if their degree of correlation differ (Appendix Table 18). Some parameters would be mentioned as follows:-

Root fresh weight of cutting was significantly and positively correlated to all shoot and root characters while root volume had no clear relationship among any growth parameters.

Correlation analysis showed that percent rooting was significantly and highly affected with shoot girth (0.43*), shoot number (0.46**) and leaf number (0.47**). Root number was also very highly and significantly correlated with leaf area (0.56***) and root length (0.51***) whereas, leaf area, was similarly correlated with leaf number (0.64***). On the other hand, root dry weight was very highly and significantly correlated with percent rooting (0.519***), leaf number (0.524***), shoot dry weight (0.577***), root fresh weight and shoot fresh weight (0.624***) of cuttings.

Shoot dry weight was strongly and significantly correlated with shoot fresh weight (0.89***) which had a direct influence on shoot parameter that mainly contributes for the rooting ability of cuttings.

5. SUMMARY AND CONCLUSION

Ethiopia is the primary centers of origin for Arabica coffee (*Coffea arabica* L.) which is the single most important cash crop contributing a lion's share to the country's economy. Ethiopia is currently the third largest coffee producer worldwide and the average annual production amounts to about 270,000 metric tons. The majority (95%) of coffee production in Ethiopia is produced by smallholder farms and the current contributions of coffee is more than 35% of the country's foreign exchange earnings, over 5% of the GDP, 12% of the agricultural output, and 10% of the government revenues. It also employs 25% of the domestic labour force. About 1.2 million coffee farmers with their 15 million households directly or indirectly depend on coffee for their livelihoods.

Despite the significant role that coffee plays in the economy of the country, the crop suffers from many production constraints affecting both in yield and quality. The national average coffee yield of Ethiopia is low and 710 kg ha^{-1}. The three high yielder (20-26qt/ha) hybrid coffee varieties (Aba-buna, Melko-CH2 and Gawe) which were recently released by EIAR can be exploited to fill the gap of low production volume. However, their multiplication by seed gets difficulty to reach the users and some methods, such as grafting, budding and tissue culture, need skilled personnel to follow propagation by cutting is one means of reproduction which ensures genetic purity. The success of rooting of stem cutting in previous work done in Ethiopia did not exceed 89 % with mist propagator and the study did not include other high yielder released Ethiopian arabica coffee hybrids such as Gawe and Melko-CH2, cutting types with different leaf retentions; and synthetic plant rooting hormones.

The present study was, therefore, initiated with the objective to determine the best rooting hormones (IBA and NAA) and level of leaf retention which help in

establishing a simple and reliable vegetative propagation method using semi hard wood stem cuttings of released hybrid coffee varieties by evaluating the rooting ability and growth performance of the cuttings.

In this experiment, three hybrid coffee varieties, two cutting types and three level of hormone treatment were tested. Coffee hybrids evaluated were Aba-buna, Gawe and Melko-CH2. The two types of cuttings, six month aged full node cuttings with single leaf or with a pair of leaves retention were treated with distilled water, IBA and NAA each with concentration of 400-ppm making the total treatment combinations eighteen. Factorial combination of the three factors was laid down in RCBD with three replications in a lath house at JUCAVM.

Results of the experiment showed that percent rooting of cuttings was significantly ($P \leq 0.05$) affected by application of rooting hormones. It was observed that IBA treated single node semi-hard wood cuttings with a pair of leaves retention had rooted (97.53 %) better than cuttings with single leaf retention and treated with IBA and NAA and those with a pair of leaves treated with NAA. Percentage of rooting was significantly higher for Gawe hybrid coffee variety treated with both IBA (94.44 %) and NAA (89.81%), and Aba-buna treated with IBA (92.59%).

Application of IBA significantly($P \leq 0.05$) increased shoot number, root number, root volume, total leaf area and root fresh weight, but did not affect leaf number, shoot and root dry weight and shoot fresh weight.

Shoot girth, root length, root number and root girth were significantly ($P \leq 0.05$) influenced by both rooting hormones (IBA and NAA). Cuttings with a pair of leaves were observed to have higher shoot girth, root girth (2.67mm), and leaf number.

Variety Aba-buna exhibited significantly ($P \leq 0.05$) better root girth, root length, root dry weight and shoot height than did Gawe and Melko-CH2. Moreover, better shoot fresh and dry weights were recorded for cuttings having a pair of leaves.

Gawe with a pair of leaves grew much more primary roots (4.67) than did other varieties with either single or a pair of leaf retention. Its response to IBA for both shoot and root parameters was better than to NAA while hybrid Melko-CH2 was poorly responded to these rooting hormones.

The highest value of root to shoot ratio was observed for cuttings with a pair of leaf retention and for varieties Gawe and Aba-buna cuttings treated with IBA.

Application of IBA increased the total dry weight of Gawe cuttings but did not affect that of Aba-buna and Melko-CH2. On the other hand, variety Aba-buna with a pair of leaves exhibited the highest total dry matter yield than did Gawe and Melko-CH2.

The results obtained from the present study have therefore shown that vegetative propagation of hybrid coffee (Aba-buna and Gawe) could be successfully attained by application of rooting hormones (IBA and NAA) to semi hard wood single nodal cuttings having a pair of leaf retention and directly inserting the cuttings in the polybags filled with conventional coffee nursery media. Moreover, the system does not require heavy capital investments and it could be located anywhere with ease.

However, it was suggested that further investigations focusing on different concentrations of hormones, (especially for varieties such as Melko-CH2), cost benefit analysis, use of alternatives for rooting media and hormones, and evaluation of field performance of the cuttings, would be important to come up with a more comprehensive conclusion and recommendation.

Future Direction

The present investigation provided information not only to prefer appropriate rooting hormones, but also the information about the differences rooting ability of hybrid coffee varieties which is believed to be important in an attempt to easy propagate (true-to-type) planting materials by stem cuttings. However, the following gaps need due consideration as future line of work:

1. Evaluation of different concentrations of IBA and NAA for hybrid coffee varieties in general and high concentrations of rooting hormones for Melk-CH2 in particular should be studied
2. Different Application methods of hormones should be studied
3. Cost benefit analysis and other alternatives of hormones should be studied
4. Rooting media mixture that may substitute forest soil and alleviate the problems related with its usage should be investigated
5. Post rooting evaluation of the cuttings including field performance after transplanting should be studied.

6. REFERENCES

Adeyemi, E.A.; Omolaja, S.S. and A.O. Famaye.(2007) The Effect of Leaf on Half-Node Stem Cuttings on the Propagation of Robusta Coffee (*Coffea canephora*) in Nigeria,Cocoa. Research Institute of Nigeria (CRIN), P.M.B.5244, Ibadan, Nigeria

Akwatulira, F. S.; Gwali2. J. B. L., Okullo. P., Ssegawa, S.B., Tumwebaze, J. R. Mbwambo and A., Muchugi. 2011. Influence of rooting media and indole- 3-butyric acid (IBA) concentration on rooting and shoot formation of *Warburgia ugandensis* stem cuttings, *African Journal of Plant Science* Vol.5(8), pp. 421-429

Alemayehu T, Esayas K, Kassu, K. (2008). Coffee development and marketing improvement plan in Ethiopia. pp: 375-381. Coffee Diversity & Knowledge. Proceedings on Four Decades of Coffee Research and Development in Ethiopia, A National Workshop, 14-17 August 2007, *Ghion* Hotel, Addis Ababa, Ethiopia.

Ampofo, S.T. and Osei-Bonsu K. 1988. A practical guide for coffee extension workers. Tech. Bulletin, Cocoa Research Institute of Ghana (CRIG), Tafo.

Anuradha,K. and M.S. Sreenivasan. 1993. Studies on rooting ability of Cauvery (Catimor) cuttings. J. Coffee Res. 23:55-58.

Arega zeru, 2008. Diversity of coffee population in afromontane rain forests of Ethiopia in relation to *colletorichum kahawae.* Msc. Thesis, Addis Ababa University Ethiopia

Badji, S.; I. Ndiaye, P. Danthu and J. P. Colonna1.1991.Vegetative propagation studies of gum arabic trees.1. Propagation of *Acacia senegal* (L.) Willd. using lignified cuttings of small diameter with eight nodes. Agroforestry Systems 14**:** 183-191.

Bayetta Belachew, Behailu Atero and Fekadu Tefera, 2000. Breeding for the resistance to coffee berry disease in Arabica coffee: progress since 1973. In: *proceedings of the workshop on control of coffee berry Disease (CBD) in Ethiopia*, 13-15August 1999, Addis Ababa, Ethiopia. pp. 85-97.

Bayetta Belachew, 2001. Arabica coffee breeding for yield and resistance to coffee Berry disease (*Colletotrichum kahawae* sp.nov.). *Doctoral Dissertation*. Imperial College at Wye University of London. 272 pp.

Behailu, A.; Gibramu T. and B, Bayetta. 2004. Effect of type of cutting and media mixture on rooting ability of arabica coffee hybrid. Crop Science Society of Ethiopia. Eleventh conference proceeding. Addis Ababa, Ethiopia. Pp 135-138.

Behailu, A.; Bayetta B, Fikadu.T, Melaku.A, Tadesse B., and Ashenafi. A. 2008. Developing Coffee Hybrid Varieties, pp 99-104. Coffee Diversity and Knowledge, Addis Ababa, Ethiopia.

Bertram Lise, 1991. Vegetative propagation of *Hibiscus rosa-Sinensis* L. in relation to nutrient concentration of propagation medium. *Sci. Hort.,* 48: 131-139.

Biswas, M. and Kobayashi,K.D.1995.Girdling,Wounding,Stem maturity, and IBA effects on rooting of jack fruit(*Artocarpus heterophyllus* Lam.) stem cuttings. Agri 6:19-25

Blazich, F.A. 1988. Chemicals and formulations used to promote adventitious rooting, In: T.E. Davis, B.E. Haissig, and N. Sankhla (eds.). Adventitious root formation in cuttings. Dioscorides`1 Press, Portland, Oregon. pp. 132-149.

Blythe,G. and Jeff. L. Sibley. 2003. Novel Methods of Applying Rooting Hormones in Cutting Propagation Auburn University, Horti.1-2

Bureau of Planning and Economic Development of Oromia Regional State (BPEDORS). 2000. Annual Report, Addis Ababa. pp35

Burdett, A.N.1990. Physiological processes in plantation establishment and the development of specifications for forest planting stock.*Canadian Jouranal of forest Research* 20:415-427.

Braun, H. 2007. Evaluation of the growth of stem shoots of the *coffea canephora* variety 'Conilon' under different shade levels. Idesia, V. 25, (3), p. 85-91

Cambrony, H.R. 1992. *Coffee growing*. The tropical agriculturist, Macmillan, London and Basing stoke. pp 21-29

Central Coffee Research Institute (CCRI).2003.'Coffee Guide'., Chikmagalur District, Karnataka, India. 200p

Chalapathi, M. V., Kumar, N. D., Gangadhar, G. E. and Jayaramaiah, R. 1999. Comparative performance of plant and ratoon crops of Stevia (*Stevia rebaudiana*). *Indian Agric*., 43: 211-212.

Chalapathi, M.V.; Thimmegowda, N.D., S., Kumar, Gangadhar, G., Rao, E. and Mallikarjun,K. 2001. Influence of length of cutting and growth regulators on vegetative propagation of Stevia (*Stevia rebaudiana* Bert.). *Crop Res*., 21: 53-56.

Carvalho, M. D., Zaidan, L. and De, C. M. 1995. Propagation of *Stevia rebaudiana* from stem cuttings. *Persquisa-agropecuaria-brasileira*, 30: 201-206.

Cohen, E., S. Arad, Y.M. Heimer, and Y. Mizrahi. 1984. Polyamine biosynthetic enzyme in the cell cyc1e of *Chlorella vulgaris*. Plant Physiol. **74:** 385_388.

Copper, W.C.1935. Hormone in relation to root formation on stem cuttings. Plant Physio.10: 789-794

Copes, D.L, and N.L. Mandel. 2000. Effect of IBA and NAA treatments on Douglas-fir stem cuttings. *New forests* 20: 249-257

Coste, R. 1992. Coffee. The plant and the product. Macmillan, pp328.

Davis, D.T and B.E. Hassing. 1990. Chemical control of adventitious root formation in cuttings. Bull: Plant Growth Reg.Soc.Am, 18: 1-17

Davies, P.J. 2004. Plant hormones: Biosynthesis, Signal Transduction, Action! Dordrecht, Kluwer Academic Publishers, The Netherlands

Davis, A.P., Govaerts, R., Bridson, D.M. and Stoffelen, P. (2006). An annotated taxonomic conspectus of the genus *Coffea (Rubiaceae*). *Botanical Journal of the Linnean Society*.**15:** 465 – 512.

Davis, A.P., Chester, M., Maurin, O., and Fay, M.F. (2007). Searching for the relatives of *Coffea* (*Rubiaceae, Ixoroideae*). The circumscriptions and phylogeny of *Coffea* based on plasmid sequence data and morphology. *Ame. J. of Bot.* **94 (3)**: 313 – 329.

Debnath, M. 2008, Clonal propagation and antimicrobial activity of an endemic medicinal plant *Stevia rebaudiana. J of Medicinal Plant. Res.*, **2**(2): 45-51.

DFID. 2004. Rethinking Tropical Agricultural Commodities. London: Department for International Development.

Dietz, A., U. Kutschera, and P.M. Ray. 1990. Auxin enhancement of mRNAs in epidermis and internal tissue of the pea stem and its significance for control of elongation. Plant Physiol. **93:** 432_438.

Eastern African Fine Coffees Association (EAFCA). 2010. EAFCA Coffee Outlook 2010

Ethiopian commodity Exchange (ECX). 2008. Analysis of Coffee Supply, Production, Utilization and Marketing Issues and Challenges in Ethiopia. Planning & Economic Analysis, Ethiopia Commodity Exchange Authority, Addis Ababa, Coffee Profile *Vol. I.* pp4.

Ethiopian Institute of Agricultural Research (EIAR). 2008. Coffee Diversity and Knowledge, Proceeding of a National Workshop, Ethiopia, 219-221

Fahl, J.I., and Carelli, M.L.C.1994. Influence of shade levels to adaptability of *coffee* plants and different irradiance Londrina, Anais.Londrina: IAP, p. 289

Farooqi, A. A., Shenoy, R. and Ramu, B. S. 1994. Influence of planting material and growth regulators on the rooting of cutting of *Rosa damascena* Mill.*Indian Perfumer*, 38: 133-143.

Farr, D.F.; Bills G.F., Chamris, G.P and Rossman, A.Y. 1989. Fungi on plants and plant products in the united state. The America philological society st. Paul. Minnesota 637-640

Gole, T.W.; Denich, M. Demel T. & Vlek, P.L.G. 2002. Human impacts on Coffea arabica genetic pool in Ethiopia and the need for its in situ conservation. CAB International / IPGRI, Rome, pp. 237-247

Govinden-Soulange, J. N. Boodia, C. Dussooa, R. Gunowa, S. Deensah, S. Facknath and B. Rajkomar (2009). Vegetative Propagation and Tissue Culture Regeneration of *Hibiscus sabdariffa* L. (Roselle) World Journal of Agricultural Sciences 5 (5): 651-661

Grundy, S. 2005. It's not just about the money: An evaluation of the impact of fair trade on improving the livelihoods of smallholder coffee farmers in Oromia Region, Ethiopia. Dissertation submitted in partial fulfillment of the requirements of the Masters of Science degree in poverty reduction and development management of the University of Birmingham.

Hallam**,** D**.** 2003. Falling commodity prices and industry responses: some lessons from the international coffee crisis. FAO. Rome.

Harold, D.; Curtis, P. and Roy, M. 1994. Nursery Management Administration and Culture.3rd ed. Prentice Hall, Inc. USA.pp.437-453

Hartmann, Hudson. T.1975. Plant Propagation. Prentice-Hall, Inc. p.662.

Hartman, H. T. and Kester D. E. 1983. Plant propagation principles and practices (4th Ed.) Prentice-Hall Inc. En.elewood Cliff PP. 250-264.

Hartmann HT, Kester DE, Davies FT (1990). Plant Propagation: Principles and Practices. Prentice Hall, Englewood Cliffs, NJ 5th ed., p. 647.

Hartmann, H.T.; D.E. Kester, F.T. Davies, Jr., and R.L. Geneve. 1997. Plant propagation principles and practices.6th ed. Prentice Hall,Upper Saddle River, New Jersey.

Hartmann, H.T.; Kester, D.E., Davies. F.T., Geneve. R.L. 2002. Plant Propagation Principles and Practices. 7th Edition. Prentice Hall. New Jersey, pp. 367-374.

Heinz,L., Hertman,.V and guttenberg.1962. Peroxidase isoenzymes as marker for the rooting ability and difficult- to- root Grevillea species and cultivars of Protea obstusifolia (Proteacae) jutta Ludwing-Muller. *Planta*.Volume58, No.5, pp 471-482.

Hirunpanich, V., A. Utaipat, N.P. Morales, N. Bunyapraphatsara, H. Sato, A. Herunsale and C.H. Suthisisang, 2006. Hypocholesteromic and antioxidant effects of aqueous extracts from the dried calyx of *Hibiscus sabdariffa* L. in hypercholesteromic rats. J. of Ethnopharmacology, 103: 252-260.

Institute of Agricultural Research (IAR). 1997. Jimma National Coffee Research Center, Progress report for the period 1994 (Part 1 Coffee). Melko, Ethiopia.

International Coffee Organisation (ICO) 2005. Trade statistics. July 2006 Monthly Report. London

International Coffee Organisation (ICO). 2012. Coffee Market report, Trade statistics. Letter from the Executive Director, London

Irulappan, I., Ponnuswamy, V., Vadivel, E. and Dharmaraj, G. 1982. Sensitivity studies in Pepper (*Piper nigrum* L.) *South Indian Hort*. 30 : 51-53.

Kaur-Sawhney, R., H.E. Flores, and A.W. Galston. 1980. Polyamine induced DNA synthesis and mitosis in Oat leaf protoplast. Plant Physiol. **65:** 368_371.

Kepinski, S. and Leyser, O. 2005. Plant development: auxin in loops. Curr Biol 15(6):208-210.

Kester, D.E, Hartmann, T.H. and Davier, F.T. 1990. Plant propagation: Principles and Practices.5th edition. Prentice Hall, Singapore, p. 647.

Labouisse,J.P.,B.bellachew,S.Kotecha and B.Bertrand,2008.Current status of coffee(*Coffea arabica* L) genetic resources in Ethiopia: Implication for conservation. Genet., Resour. Crop Evol.,55:1079-1093.

Lal.S . J.P. Tiwari, P. Awasthi, and G. Singh. 2009. Effect of IBA and NAA on rooting potential of stooled shoots of guava (psidium guajava l.) cv. sardar ISHS. *Acta Horticulturae* 735: I International Guava Symposium Plant Tissue Cult. & Biotech. 19 (2): 127-132

Lashermes, P., S. Anderzewski, B. Bertrand, M.C. Combes, S. Dussert, G. Graziosi,P. Trouslot and F. Anthony, 2000a. Molecular analysis of introgressive breeding in coffee (*Coffea arabica* L.). Theoretical and Applied Genetics 100: 139-146.

Laubscher C. P. and P. A. Ndakidemi. 2008. Rooting success using IBA auxin on endangered *Leucadendron laxum* (PROTEACEAE) in different rooting mediums, *African Journal of Biotechnology* Vol. 7 (19), pp. 3437-3442

Larsen, F.E, Guse, W.E.1997. Propagating deciduous and evergreen shrubs, trees and vines with stem cuttings. A Pacific Northwest Cooperative Extension Publication, Washington, USA, p. 10.

Leakey, R.R.B. (In press). *Nauclea diderrichii:* rooting stem cuttings, clonal variation in shoo dominance and branch plagiotropism, *Trees:* Leakey, R.R.B. and Longman, K.A. (1988). Low-tech cloning of tropical trees, *Appropriate Technology*, 15: 6.

Leakey, R.R.B. and Coutts, M.P.1989. The dynamics of rooting in *Triplochiton scleroxylon* K. Schum. cuttings - their relationship to leaf area, node position, dry weight accumulation, leaf water potential and carbohydrate composition. *Tree Physiology,* 5: 135 -146

Mawardi S., and B. Purwadi. 2004. Genetic of Rooting and Sprouting Abilities on Cuttings Propagation of Robusta Coffee Clones (*Coffea canephora* Pierre var. *robusta* Cheval). Indonesia Coffee and Cocoa Research Institute (ICCRI), Jalan PB SudirmanNo. 90, Jember 68118, Indonesia

McGuire, J.J. 1967. Entrance of synthetic growth regulator IAA-2-14C into cuttings of *Ilexcrenata* 'Convexa'. Comb. Proc. Intl. Plant Prop. Soc. 17:322-327.

Mc Guire, J.J. and D.C. Sorensen.1966. Effect of terminal applications of IBA on rooting of woody ornamental plants. Comb. Proc. Intl. Plant Prop. Soc. 16:257 260.

McMillan, M., Assefa T, Yohannes A, Kibre M and Amdissa T. 2003. ETHIOPIA: Trade and Transformation Challenges. Agriculture and Trade Diagnostic Trade Integration Study. Annex 8, Volume 2, Addis Abeba, Ethiopia.

Mekuria, T., Neuhoff D. and Köpke U, 2004. The Status Of Coffee Production And The Potential For Organic Conversion In Ethiopia. Conference on International Agricultural Research for Development. University of Bonn, Institute of Organic Agriculture.; 2

Middleton, W., B.C. Jarvis and A. Booth.1980. The role of auxin in leaves and boron dependant on rooting of stem cuttings of phaseous aureus roxb. New phytologist,84: 251-259

Nelson LM. 2004. Plant growth promoting rhizobacteria (PGPR): Prospect for new inoculants. Online. Crop Management doi: 10. 1094/CM-2004-0301-05-RV.

Newton, A.C; Mesen J.F, Dick J.Mc.P, Leakey R.R.B. 1992. Low technology propagation of tropical trees: Rooting physiology and practical implications. In: Mass production technology for genetically improved fast growing forest tree species. AFOCEL, Nangis, France, **2**: 417-424.

Nordstrom A-C, Jacobs FA, Eliasson L. 1991. Effect of exogenous indole-3-acetic acid and indole-3-butyric acid on internal levels of the respective auxins and their conjugation with aspartic acid during adventitious root formation in pea cuttings. Plant Physiology 96, 856–861.

NRI. 2006. The Potential for Diversification in Coffee Exporting Countries. Project ICO/CFC/10FT. Report prepared for the International Coffee Organization and the Common Fund for Commodities. London: Natural Resources Institute

Oloyede, A.A.; A.O. Famaye, and S.S. Omolaja. 2004. Effect of Rooting Media, Hormone and Half-node Cutting Types on Vegetative Propagation of *Coffea canephora* 56Pierre ex. Froehner Cocoa Research Institute of Nigeria, CRIN, Ibadan, Nigeria

Omolaja, S.S. and Obatolu, C.R. 1999. Effect of rooting solutions and seasonal changes on stem cuttings propagation of *robusta* coffee (*C. canephora)*. Nigerian Journal of botany:12, No2,115-120.

Oxfam. 2002b. Mugged: Poverty in your Coffee Cup. Oxfam International

Osei-Bonsu. K. 1992. The Effect of Different Media on the Success of Rooting Ramets of Coffee Clones Directly in Polybags Cocoa Research Institute of Ghana, P.O. Box 8, Tafo-Akim, Ghana.

Panwar, R.D.; Kaushik, R.A., Singh, S and Gupta, R.B. 2001. Effect of IBA on rooting of hardwood cuttings of pomegranate (*Punica granatum* L.) Haryana J. Hort. Sci. 30(1&2): 72.

Petit, N., 2007. Ethiopia coffee sector: A bitter or a better future .J. Agrarian Change, 7:225-263.

Rathore, D.S. 1984. Propagation of Chinese gooseberry from stem cuttings. Indian J. Hort. 43(3&4):237-239.

Rezende, T. T.; Baliza, D.P. Oliveira, D.H. Carvalho, S.P. Avila, F.W. Passos, A.M.A.6 Guimaraes,R.J. 2010. Types of Stem Cuttings and Environments on the Growth of Coffee Stem Shoots. *Scientia Agraria* ISSN : 1519-1125. 4

Silvarolla, M.B., P. Mazzafera and L.C. Fazuoli, 2004. A naturally decaffeinated arabica coffee. Nature 429: 826.

Singh, A. K.; Rajesh Singh, Mittal, A. K., Singh, Y. P. and Shiva Jauhari. 2003. Effect of plant growth regulators on survival rooting and growth characters in long pepper (*Piper longum* L.). *Prog. Hort.*, **35**: 208-211

Taye K. and Tesfaye S. 2002. Organic coffee production: hope for small-scale farmers in Ethiopia. Proceedings of the 19th International Conference on Coffee Science (ASIC), May 14-18, 2001, Trieste, Italy.

Tchoundjeu, Z.; Ngo Mpeck, M.-L., Asaah, E., Amougou, A., 2004. The role of vegetative propagation in the domestication of Pausinystalia johimbe (K. Schum), a highly threatened medicinal species of West and Central Africa. For. Ecol. Manage. 188, 175–183.

Tefestewold Biratu .1995. Studies on colletorichum population of *coffee Arabic* .L in Ethiopia and evaluation of population of coffee germ plasm PhD.Diss. University of Bonn, Germany.

Tesfaye S. 1995. Influence of nursery watering frequency, moisture status of ooting media and media moisture conservation on growth of coffee (*Coffea arabica* L.) seedlings. M.Sc thesis, Alemaya University of Agriculture, 112 pp.

Tesfaye, S. 2005. Growth, water relations, yield and crop quality of Arabica coffee in response to water stress and deficit irrigation. PhD Dissertation. University Putra Malaysia (UPM).

USDA. 2006. Tropical Products: World Markets and Trade. Washington: United States Department of Agriculture, Foreign Agricultural Service. Circular Series FTROP 2-06.

Van Bragt, J., H. Van Gelder, and R.L.M. Pierik. 1976. Rooting of shoot cuttings of ornamental shrubs after immersion in auxin-containing solutions. Scient. Hort. 4:91-94.

Verheij, E.d. 2004. Propagating and planting trees. Agrodock(19), *Agromisa Foundation*, Wageningen, pp37

Vossen.V., H.2002. Coffee Selection and Breeding in Coffee Botany, Biochemistry and Production of Beans and Beverage; eds MN Clifford and KC. Wilson Croon Helm, London.

Wamatu and King'oro. 1992. Vegetative propagation of cultivar ruiru11 by rooting softwood stem cuttings. *Kenyan Coffee* 57: 1399–1404.

Wamatu, J.N. 1993. Rooting propensity and shade requirements of coffee Arabica cultivar Ruiru stem cuttings, *Kenya coffee* 58:1615-1618

Wilson, P.J.1993. Propagation characteristics of Eucalyptus globules Labill. Spp. globules stem cutting in relation to their orginal position in the parent shoot. Journal of Horticultural Science, 68(5):715-724)

Woldemariam, T., M. Denich, D. Teketay and P.L.G. Vlek, 2002. Human impacts on *Coffea arabica* L. genetic pools in Ethiopia and the need for its *in situ* conservation. In: J.M.M. Engels, V.R. Rao, A.H.D. Brown and M.T. Jackson (Eds.), Managing plant genetic diversity, IPGRI, Rome. Pp. 237-247.

Wondyifraw, T.; Ramos A., Alemayehu, T. and Zerihun, A. 2008. Tissue CultureMultiplicationTechniques for Coffee. Pp106 – 107. Proceeding of a National Workshop four Decades of Coffee Research and Development, Coffee Diversity and Knowledge, Addis Ababa, Ethiopia.

Wood, A.J. and Roper, J. 2000. A Simple and Nondestructive Technique for Measuring Plant Growth and Development. *American Biology Teacher,* V62 n3 p215-17.

Wrigley, G. 1988. Coffee. Tropical Agriculture Series, London, John Wiley and Sons,Inc., Nw York.; 63

7. APPENDICES

Appendix Table 1 Physico-chemical analytical result of rooting Media (Soil) during insertion of cutting

Description	Values	Remark
pH	5.97	
Nitrogen (%)	0.192	
Available Phosphorus	10.3 (ppm, bray)	
Available Potassium	875 ppm	2.24 K(Meg/100gm)
Cation exchange capacity	29.62	CEC(Meg/100gm)1
Bulk density	1.7(gm/cm^3)	
Texture	Sand clay Loam	(46,28,26)
Porosity	35.85%	
Electric conductivity	0.483 ms/cm	
Organic carbon	2.38%	
Organic matter	4.10%	
Moisture content	70%	

Key- Soil Depth is 0-20cm

Appendix Table 2 Analysis of variance for interaction effect of hybrids and hormones on per cent of rooting

Source of Variation	df	SS	MS	F-value	Pr >F
Block	2	175.78	87.79	1.89	0.1663
Hybrids	2	475.73	237.87	5.12	0.0114
Leaf retention	1	1473.50	1473.50	31.72	<.0001
Hormones	2	908.89	454.45	9.78	0.0004
Hybrids *Leaf retention	2	174.08	87.04	1.87	0.1691
Hybrids * Hormones	4	605.83	151.4	3.26	0.0229
Leaf retention *Hormones	2	344.35	172.18	3.71	0.0350
Hybrids*Leaf retention *Hormones	4	472.52	118.13	2.54	0.0574
Error	34	1579.43	46.46		
Total	53	6210.17			

Appendix Table 3 Analysis of variance for the effect of rooting hormone and leaf retention on shoot number per cutting

Source of Variation	df	SS	MS	F-Value	Pr >F
Block	2	0.109	0.054	2.63	0.0870
Hybrids	2	0.075	0.037	1.8	0.1814
Leaf retention	1	0.051	0.051	2.47	0.1253
Hormones	2	0.161	0.081	3.85	0.0310
Hybrids *Leaf retention	2	0.029	0.014	0.71	0.4995
Hybrids * Hormones	4	0.105	0.026	1.26	0.3050
Leaf retention *Hormones	2	0.004	0.002	0.11	0.8956
Hybrids*Leaf retention *Hormones	4	0.139	0.035	1.67	0.1789
Error	34	0.711	0.021		
Total	53	1.388			

Appendix Table 4 Analysis of variance for the effect of hybrid varieties, rooting hormone and leaf retention on shoot girth per cutting (mm)

Source of Variation	df	SS	MS	F-Value	Pr >F
Block	2	14.65	7.32	51.05	<.0001
Hybrids	2	0.09	0.05	0.33	0.7223
Leaf retention	1	0.78	0.78	5.47	0.0254
Hormones	2	0.95	0.48	3.33	0.0477
Hybrids *Leaf retention	2	0.67	0.33	2.33	0.1129
Hybrids * Hormones	4	0.60	0.15	1.05	0.3969
Leaf retention *Hormones	2	0.23	0.01	0.09	0.9100
Hybrids*Leaf retention *Hormones	4	0.59	0.39	2.76	0.0432
Error	34	4.88	0.14		
Total	53	24.24			

Appendix Table 5 Analysis of variance for the effect of variety, rooting hormone and leaf retention on leaf number per cutting

Source of Variation	df	SS	MS	F-Value	Pr >F
Block	2	239.38	119.69	1.34	0.2761
Hybrids	2	58.21	29.11	0.33	0.7247
Leaf retention	1	13.42	13.42	0.15	0.7011
Hormones	2	1419.91	709.96	7.93	0.0015
Hybrids *Leaf retention	2	482.92	241.46	2.70	0.0818
Hybrids * Hormones	4	153.37	38.34	0.43	0.7872
Leaf retention *Hormones	2	22.78	11.39	0.13	0.8810
Hybrids*Leaf retention *Hormones	4	174.53	43.63	0.49	0.7449
Error	34	3044.15	89.53		
Total	53	5608.67			

Appendix Table 6 Analysis of Variance for the effect of variety, hormone and leaf retention on total leaf area of cuttings (cm^2)

Source of Variation	df	SS	MS	F-Value	Pr >F
Block	2	0.74	0.37	0.23	0.8987
Hybrids	2	10.35	5.17	3.16	0.0550
Leaf retention	1	16.54	16.54	10.11	0.0031
Hormones	2	21.47	10.73	6.56	0.0039
Hybrids *Leaf retention	2	3.65	1.83	1.12	0.3392
Hybrids * Hormones	4	1.71	0.43	0.26	0.9009
Leaf retention *Hormones	2	1.11	0.56	0.34	0.7140
Hybrids*Leaf retention *Hormones	4	5.64	1.41	0.86	0.4970
Error	34	55.62	1.63		
Total	53	116.84			

Appendix Table 7 Analysis of variance for the effect of coffee hybrid variety on shoot height per cuttings

Source of Variation	df	SS	MS	F-Value	Pr >F
Block	2	3.17	1.56	1.27	0.2933
Hybrids	2	26.17	13.08	10.49	0.0003
Leaf retention	1	0.00	0.00	0.00	0.9788
Hormones	2	6.43	3.22	2.58	0.0907
Hybrids *Leaf retention	2	1.71	0.86	0.69	0.5105
Hybrids * Hormones	4	3.78	0.95	0.76	0.5596
Leaf retention *Hormones	2	2.00	1.00	0.80	0.4567
Hybrids*Leaf retention *Hormones	4	5.88	1.47	1.18	0.3374
Error	34	42.41	1.25		
Total	53	41.56			

Appendix Table 8 Analysis of variance for the interaction effect of hybrids, leaf retention and rooting hormones on shoot fresh weight (gm) of cuttings

Source of Variation	df	SS	MS	F-Value	Pr >F
Block	2	0.19	0.09	1.07	0.3547
Hybrids	2	1.69	0.84	9.59	0.0005
Leaf retention	1	1.28	1.28	14.40	0.0006
Hormones	2	1.89	0.94	10.66	0.0003
Hybrids *Leaf retention	2	1.23	0.62	6.96	0.0029
Hybrids * Hormones	4	2.08	0.52	5.88	0.0010
Leaf retention *Hormones	2	0.01	0.01	0.08	0.9200
Hybrids*Leaf retention *Hormones	4	0.45	0.11	1.29	0.2936
Error	34	3.01	0.09		
Total	53	11.85			

Appendix Table 9 Analysis of variance for the interaction effect of hybrids, leaf retention and rooting hormones on shoot dry weight(g) of cuttings

Source of Variation	df	SS	MS	F-Value	Pr >F
Block	2	1.196	0.598	5.27	0.0101
Hybrids	2	0.002	0.001	0.01	0.9886
Leaf retention	1	0.019	0.019	0.17	0.6828
Hormones	2	3.528	1.764	15.55	0.0001
Hybrids *Leaf retention	2	0.030	0.015	0.13	0.8756
Hybrids * Hormones	4	0.269	0.067	0.59	0.6688
Leaf retention *Hormones	2	0.055	9.027	0.24	0.7869
Hybrids*Leaf retention *Hormones	4	1.346	0.336	2.97	0.0333
Error	34	3.356	0.113		
Total	53	10.303			

Appendix Table 10 Analysis of variance for the interaction effect of hybrids, leaf retention and hormones on root volume (cm^3)

Source of Variation	df	SS	MS	F-Value	Pr >F
Block	2	0.007	0.003	0.41	0.6690
Hybrids	2	0.150	0.075	8.78	0.0008
Leaf retention	1	0.097	0.097	11.30	0.0019
Hormones	2	0.136	0.068	7.94	0.0015
Hybrids *Leaf retention	2	0.150	0.075	8.75	0.0009
Hybrids * Hormones	4	0.132	0.033	3.85	0.0110
Leaf retention *Hormones	2	0.001	0.001	0.08	0.9264
Hybrids*Leaf retention *Hormones	4	0.39	0.009	1.15	0.3493
Error	34	0.292	0.009		
Total	53	1.007			

Appendix Table 11 Analysis of variance for the effect of hybrids, leaf retention and rooting hormones on root number of cuttings

Source of Variation	df	SS	MS	F-Value	Pr >F
Block	2	1.58	0.79	2.48	0.0991
Hybrids	2	1.40	0.70	1.19	0.1270
Leaf retention	1	2.72	2.72	8.51	0.0062
Hormones	2	10.53	5.27	16.48	<.0001
Hybrids *Leaf retention	2	4.16	2.08	6.51	0.0040
Hybrids * Hormones	4	0.05	0.01	0.04	0.9966
Leaf retention *Hormones	2	0.33	0.16	0.51	0.6043
Hybrids*Leaf retention *Hormones	4	0.36	0.09	0.28	0.8903
Error	34	10.87	0.32		
Total	53	32			

Appendix Table 12 Analysis of variance for the effect of coffee hybrids and rooting hormones on root length(cm) of cuttings

Source of Variation	df	SS	MS	F-Value	Pr >F
Block	2	0.56	0.28	0.52	0.6012
Hybrids	2	4.32	2.16	3.98	0.0281
Leaf retention	1	0.03	0.03	0.05	0.8275
Hormones	2	49.74	24.87	45.72	<.0001
Hybrids *Leaf retention	2	0.02	0.01	0.02	0.9842
Hybrids * Hormones	4	4.61	1.52	2.12	0.1000
Leaf retention *Hormones	2	0.11	0.05	0.10	0.9021
Hybrids*Leaf retention *Hormones	4	0.25	0.06	0.11	0.9768
Error	34	18.49	0.54		
Total	53	78.13			

Appendix Table 13 Analysis of variance for the effect of hybrid varieties, rooting hormone and leaf retention on root girth per cutting (mm)

Source of Variation	df	SS	MS	F-Value	Pr >F
Block	2	0.38	0.19	2.17	12.98
Hybrids	2	1.01	0.50	5.75	0.0071
Leaf retention	1	0.94	0.94	10.73	0.0024
Hormones	2	3.32	1.66	18.86	<.0001
Hybrids *Leaf retention	2	0.08	0.04	0.45	0.6432
Hybrids * Hormones	4	0.54	0.13	1.53	0.2152
Leaf retention *Hormones	2	0.04	0.02	0.25	0.7770
Hybrids*Leaf retention *Hormones	4	0.06	0.01	0.16	0.9551
Error	34	2.99	0.09		
Total	53	9.37			

Appendix Table 14 Analysis of Variance for the interaction effect of hybrids, leaf retention and hormones on root fresh weight per cutting (gm)

Source of Variation	df	SS	MS	F-Value	Pr >F
Block	2	0.61	0.31	2.75	0.0784
Hybrids	2	0.24	0.12	1.10	0.3459
Leaf retention	1	3.76	3.76	33.75	<.0001
Hormones	2	4.37	2.18	19.65	<.0001
Hybrids *Leaf retention	2	0.23	0.11	1.03	0.3669
Hybrids * Hormones	4	0.90	0.23	2.03	0.1116
Leaf retention *Hormones	2	0.19	0.09	0.86	0.4323
Hybrids*Leaf retention *Hormones	4	1.23	0.31	2.77	0.0426
Error	34	3.78	0.11		
Total	53	15.31			

Appendix Table 15 Analysis of variance for the interaction effect of hybrid, leaf retention and rooting hormones on root dry weight of cuttings(g)

Source of Variation	df	SS	MS	F-Value	Pr >F
Block	2	0.004	0.004	0.14	0.3022
Hybrids	2	0.025	0.025	8.56	0.0010
Leaf retention	1	0.209	0.209	70.66	<.0001
Hormones	2	0.034	0.017	5.77	0.0070
Hybrids *Leaf retention	2	0.022	0.011	3.81	0.0321
Hybrids * Hormones	4	0.036	0.009	3.08	0.0289
Leaf retention *Hormones	2	0.004	0.002	0.66	0.5250
Hybrids*Leaf retention *Hormones	4	0.016	0.004	1.39	0.2584
Error	34	0.100	0.003		
Total	53	0.479			

Appendix Table 16 Analysis of variance for the effect of hybrid variety and leaf retention on root to shoot ratio of cuttings (dry weight base)

Source of Variation	df	SS	MS	F-Value	Pr >F
Block	2	0.014	0.007	0.46	0.6379
Hybrids	2	0.102	0.051	3.28	0.0500
Leaf retention	1	0.244	0.244	15.70	0.0004
Hormones	2	0.018	0.004	0.26	0.7688
Hybrids *Leaf retention	2	0.099	0.049	3.20	0.0534
Hybrids * Hormones	4	0.063	0.016	1.01	0.4180
Leaf retention *Hormones	2	0.004	0.002	0.12	08850
Hybrids*Leaf retention *Hormones	4	0.013	0.003	0.20	0.9356
Error	34	0.529	0.016		
Total	53	1.075			

Appendix Table 17 Analysis of variance for the effect of hybrid variety and leaf retention and hormones on total dry weight of cuttings

Source of Variation	df	SS	MS	F-Value	Pr >F
Block	2	0.021	0.011	0.078	0.4661
Hybrids	2	0.294	0.147	10.89	0.0002
Leaf retention	1	0.590	0.590	43.59	<.0001
Hormones	2	0.299	0.149	11.07	0.0002
Hybrids *Leaf retention	2	0.237	0.118	8.97	0.0008
Hybrids * Hormones	4	0.277	0.069	5.12	0.0025
Leaf retention *Hormones	2	0.007	0.003	0.27	0.7621
Hybrids*Leaf retention *Hormones	4	0.100	0.025	1.85	0.1427
Error	34	0.460	0.013		
Total	53	2.289			

Appendix Table 18 Correlation coefficient for the effect of hormones and leaf retention on rooting and growth of hybrid coffee (*Coffea arabica L.*) stem cuttings

	SN	SH	SG	LN	LA	SFW	SDW	PR	RV	RL	RN	RG	RFW	RDW
	1.000													
	0.045ns	1.00												
	0.455**	0.200ns	1.00											
	0.414*	0.029ns	0.257ns	1.00										
	0.231ns	0.342*	0.141ns	0.634***	1.00									
W	0.117ns	0.315*	0.165ns	0.458**	0.386*	1.00								
W	0.134ns	0.246ns	0.131ns	0.340*	0.363*	0.892***	1.00							
	0.464**	0.078ns	0.432*	0.474**	0.285*	0.102ns	0.096ns	1.000						
	0.086ns	0.208ns	0.015ns	0.032ns	0.182ns	0.021ns	0.054ns	0.088ns	1.00					
	0.265ns	0.426*	0.211ns	0.883ns	0.426*	0.016ns	0.054ns	0.260*	0.404*	1.00				
	0.258ns	0.213ns	0.217ns	0.355*	0.506***	0.029ns	0.068ns	0.425*	0.249ns	0.509***	1.00			
	0.280*	0.460*	0.359*	0.280*	0.320*	0.115ns	0.122ns	0.064**	0.369*	0.656***	0.352*	1.000		
W	0.266*	0.324*	0.269*	0.297*	0.279*	0.321*	0.375*	0.365*	0.504***	0.433*	0.360*	0.544***	1.000	
W	0.251ns	0.297*	0.244ns	0.524***	0.341*	0.624***	0.577***	0.519***	0.061ns	0.203ns	0.339*	0.369*	0.569***	1.000

***Remark**: SN (Shoot number), SH (Shoot height), SG (Shoot girth), LN (leaf number), LA (Total leaf area), SFW (Shoot fresh weight), SDW (Shoot dry weight), PR (Percent rooting), RV (Root volume), RL (Root length), RN (Root number), RG (Root girth), RFW (Root fresh weight) and RDW (Root dry weight)*

LIST OF PLATES IN THE APPENDIX

Plate 1.Clonal garden of Gawe (Agobiado)

Plate 2. Three months old suckers of Aba-buna

Plate 3. Six months old suckers ready for harvesting

Plate 4. Arranged pots ready for cutting insertion

Plate 5. Plastic covered pots to protect soil loss

Plate 6.White plastic sheet covered propagation frame

Plate 7. Over view of cuttings on the rooting bed

Plate 8. Roots of cuttings with a single Leaf (left and right)

Plate 9. Roots of cuttings with pair of leaves

Plate10. Gawe cuttings with adventitious roots

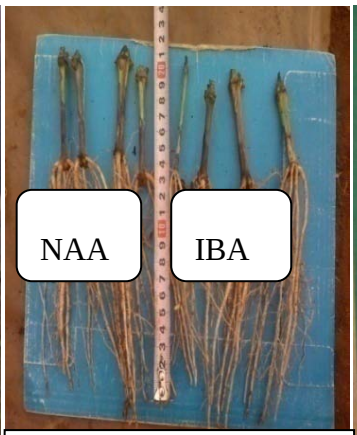


Plate 11.Roots of Aba-buna cuttings treated with IBA and NAA

Plate 12 Root of Aba-buna treated with IBA