INFLUENCE OF HARVESTING STAGES, DRYING STRUCTURES AND DRYING DURATIONS ON QUALITY OF KORARIMA (*Aframomum corrorima* (Braun) P.C.M. Jansen) IN SHEKA ZONE, SOUTHWESTERN ETHIOPIA

M.SC. THESIS

FISSIHA GEBREYSUS GEBREEGZIABHER

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JIMMA UNIVERSITY

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Submitted to the College of Agriculture and Veterinary Medicine,
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In Partial Fulfillment of the Requirements for the Degree of
MASTER OF SCIENCE IN HORTICULTURE
(COFFEE, TEA AND SPICES SCIENCE)

By

Fissiha Gebreyesus Gebreegziabher

March 2012
Jimma University

APPROVAL SHEET

SCHOOL OF GRADUATE STUDIES
JIMMA UNIVERSITY

As thesis research advisors, we hereby certify that we have read and evaluated the thesis prepared by Fissiha Gebreyesus under our guidance entitled with "**Influence of Harvesting Stages, Drying Structures and Drying Durations on Quality of Korarima (***Aframomum corrorima* (Braun) P.C.M. Jansen**) in Sheka Zone, Southwestern Ethiopia".** We then recommended that it be accepted as fulfilling of the thesis requirement for the degree of Master of Science.

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

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Internal Examiner	Signature	Date

DEDICATION

I dedicate this thesis manuscript to my Mom and Brothers who played indispensable role and planted the seed of Wisdom within me, from which my thirst for knowledge grew. It was during the thesis work I regrettably disturbed by the death of my dear mother and withdraw of my dear brother from his academic study.

STATEMENT OF THE AUTHOR

First, I declare that this is my thesis work and that all sources of materials for this thesis have been duly acknowledged. This thesis has been submitted in partial fulfillment of the requirements for the M.Sc. degree at Jimma University and is deposited at the University Library to be made available to borrowers under rules and regulations of the university and the country. I gravely declare that this thesis is not submitted to any institution, bureau, anywhere for the award of any academic degree, diploma, or certificate.

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BIOGRAPHICAL SKETCH

The author Fissiha was born from his father Mr. Gebreyesus G/Egziabher and mother Mrs. Mitsilal Aregawi in 1985 in Hawzen Woreda, Tigray Region, Ethiopia. He attended his Elementary School in Tsehafiwordi from 1994 to 2000. Then he attended his secondary and preparatory education at Masho Secondary and Edagahamus Senior Secondary Schools from 2001 to 2004, respectively.

He then joined Haramaya University in December 2004 and graduated with Bachelor of Sciences Degree (B.Sc.) July 2007. The Ministry of Education in Ethiopia employed and assigned him to Wollega University September 2007 where he served as a Graduate Assistant in Horticulture and Plant Sciences till he joined the School of Graduate Studies at Jimma University, College of Agriculture and Veterinary Medicine, in September 2009 to pursue his Master of Science Degree (M.Sc.) in Horticulture (Coffee, Tea and Spices Science).

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LIST OF ACRONYMS AND ABBREVIATIONS

ACP	Agricultural Commodities Program
AIA	Acid Insoluble Ash
CFTRI	Central Food Technological Research Institute
CSA	Central Statistics Agency
EARO	Ethiopian Agricultural Research Organization
EHSS	Ethiopian Horticultural Science Society
EO	Essential Oil
ESA	European Spice Association
ESEF	Ethiopian Spice Extraction Factory
EU	European Union
FAO	Food and Agriculture Organization
FBC	Full Bright Consultancy
GC-MS	Gas Chromatography-Mass Spectrometry
IBCR	Institute of Biodiversity Conservation and Research
ICS-UNIDO	United Nations Industrial Development Organization and the International Centre for Science and High Technology
ISO	International Standards Organization
IOSTA	International Organization of Spice Trade Associations
JUCAVM	Jimma University College of Agriculture and Veterinary Medicine
K	Kefeennono
NTFP-PFM	Non-Timber Forest Products and Participatory Forest Management
Pvt. Ltd	Private Limited
PRA	Participatory Rural Appraisal
RPM	Revolutions Per Minute
SAS	Statistical Analysis Software
SNNPR	Southern Nations, Nationalities, and Peoples Region
SNV	Netherlands Development Organization
TCPDE	Tepi Coffee Plantation Development Enterprise
TNSRC	Tepi National Spices Research Center
UNIDO	United Nations Industrial Development Organization
USDA-ARS	United States Department of Agriculture-Agricultural Research Service
USD	United States Dollar
V	Volume
W	Weight

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ABSTRACT

*Korarima (Aframomum corrorima) is native crop to Ethiopia which is used as spice and medicinal. It is one of the few under-exploited spices with promising economic value. As a result, there is a huge problem of quality. The capsules are harvested mostly at mature green stage. Besides use of different drying structures and drying durations are other big quality influencing issues. Thus, the current study was conducted with the objective of determining the appropriate harvesting stages, drying structures and drying durations for quality improvement of A. corrorima capsules. The experiment consisted of three harvesting stages (mature green, mature semi-red and mature red), three drying structures (cement floor, ground and raised wire mesh bed) and three drying durations (10, 15 and 20 days) laid out in 3*3*3 factorial arrangement using Completely Randomized Design with three replications. Data on physical and chemical quality of A. corrorima capsules were recorded and subjected to ANOVA. The results of this experiment indicated that the various harvesting stages significantly influence physical quality of fresh capsules. The combined effects among harvesting stages, drying structures and drying durations showed significant variations on physical and chemical quality. Mature green capsules dried on wire mesh for 10 days scored maximum total ash (5.45%), oleoresin (10.04%) and Essential Oil (EO) of seeds (5.53%) and husk (0.93%). Mature red capsules dried on wire mesh for 10 days recorded maximum dry weight recovery (41.30%) while mature semi-red (6.42g), mature green (6.38g) and mature red (6.32g) capsules dried on wire mesh for 10 days recorded maximum weight of seeds per capsule. On the other hand, mature green capsules dried on cement for 20 days attained minimum weight of single capsule (5.89g) and EO (2.82%). From this study, it can be concluded that wire mesh drying structure was superior to obtain overall good quality of A. corrorima capsules. Drying durations and harvesting stages depend up on the purpose of the capsules intended for final use. For immediate extraction purpose, mature green capsules dried on wire mesh for 10 days can be recommended. However, for home consumption and storage purpose, mature red capsules dried on wire mesh for 15 days can be recommended. Further investigation may need to be carried out in the aspect of production, value addition, storage shelf life and package materials.*

Keywords: Aframomum corrorima, Korarima, Quality, Essential Oil, Oleoresin, Drying Structure, Harvesting Stage, Drying Duration

1. INTRODUCTION

Spices and herbs are used throughout the world to season food products and create unique characteristic flavors of different cuisines (Parthasarathy *et al*., 2008). Today's search for unique and authentic spices is not new. In ancient times, spices were status symbols in Europe and throughout the Mediterranean for the wealthy who ate them. Spices had an enormous trade value, not only as flavoring for food, but as medicines, preservatives and perfumes (Raghavan, 2007). They have been played a dramatic role in civilization and in the history of nations (Jose and Joy, 2004). The delightful flavor and pungency of spices make them indispensable in the preparation of palatable dishes. In addition, they are reputed to posses several medicinal and pharmacological properties and hence find position in the preparation of a number of medicines (Birhanu, 2010).

The term "spice" can be defined as the dry parts of a plant, such as leaf, rhizome, pod, root and seeds which impart to food a certain flavor and pungent stimuli (Tainter and Grenis, 2001; Jose and Joy, 2004). By clubbing spices and condiments into one group, the term spice or condiment applies to 'natural plant or vegetable products or mixtures thereof, in whole or ground form, used for imparting flavor, aroma and piquancy to and for seasoning food' (Jose and Joy, 2004). International Spice Group, 2004) also suggested more or less a similar definition that is 'spices are any of the flavored or aromatic substances of vegetable origin obtained from tropical or other plants commonly used as condiments or employed for other purposes on account of their fragrance, preservative or medicinal qualities'. According to Australian Food Law (Jose and Joy, 2004), 'the term spice refers to plants or part of plants (possibly dried) that are used to enhance the flavor of human food'. On the other hand, the soft-stemmed plant materials used in seasoning food are classified as 'herbs' (Peter, 2004).

Korarima (*Aframomum corrorima* (Braun) P.C.M. Jansen) is a monocotyledonous spice and medicinal plant belonging to the order *zingiberales*, family *zingiberaceae* (Jansen, 1981; Hymete *et al*., 2006) which is one of the native spices belong to Ethiopia (Jansen, 2002; Eyob *et al*., 2007). Locally, korarima (*Aframomum corrorima*) is known as "*Offio (K)"* and the Wild korarima (*Aframomum spp.)* is known as "*Sheeti Oghio (K)"* (Endashaw, 2007). According to Tesfaye and Sebsebe (2009) Monkey's kororima is

known as '*Shetti Offio'* ('*Shetti'* means Monkey while '*Offio'* is korarima) for *Aframomum zambeziacum* (Baker) K. Schum. (*Zingiberaceae*) to distinguish it from *A. corrorima* (Braun) P.C.M. Jansen. Since the crop is known with different vernacular names; Korarima, Korarima cardamon, Kwererima, Kewrerima, corrorima, mesketo (in the Gamo Gofa), gaco (in the Debub Omo), mache (in the Kaffa), Oghio and Offio (in the Sheka) (Jansen, 1981; Eyob *et al*., 2008), it is preferable to use the botanical name (*Aframomum corrorima*) from here onwards. *Aframomum corrorima* is a perennial aromatic herb, terrestrial, rarely epiphytic, aromatic, with fleshy, tuberous or non-tuberous rhizomes, often with tuber-bearing roots of usually strong fibrous subterranean scaly rhizomes and with leafy false stems (ca. of 1m to2 m height) created by leaf-sheath (Hymete *et al*., 2006). In very ideal growing environments the plant can grow more than 2m (Girma *et al*., 2008). It is a close relative of the widely known Indian cardamom (*Elettaria cardamomum* Maton) (Jansen, 1981; Wondyifraw, 2004).

As indigenous spice, *A. corrorima* grows in various parts/zones in the country (Appendix Table 1); (Jansen, 1981; Edossa, 1998; Girma and Asrat, 2009 unpublished). Capsules/seeds are the economic parts of the plant (Edossa, 1998; Wondyifraw, 2004; Girma *et al*., 2008). The spice has very widespread utilization in Ethiopian and Eritrean cuisines. It is obtained from the plant's seeds (usually dried). It has been part of daily Ethiopian dish in preparation of curry powder for culinary purposes. It is mainly harvested from wildly grown plants in the forests of many places of South, Southwestern and Western parts of Ethiopia. The dried fruit mixture of different clones is sold on almost every Ethiopian market in the production areas; fresh capsules are sold too, rarely only the seeds. The seeds are used in Ethiopia to flavor all kinds of sauces locally for which they are ground and usually mixed with other spices (Jansen, 2002; Eyob, 2009). The essential oil of *A. corrorima* seeds has a typical odor, and is therefore, sometimes called 'nutmeg - cardamom' (Eyob *et al*., 2007). Thus, the seeds are also used medicinally in Ethiopia (Wondyifraw, 2004; Hymete *et al*., 2006).

Dried capsule of *A. corrorima* has highly significant economic importance for local and as export commodity in addition to various uses. Previously, Ethiopia was well-known for its considerable exports of *A. corrorima* capsules to the world market, mainly as a substitute for the Indian cardamom (Wondyifraw and Surawit, 2004; Eyob, 2009). Currently (2010/2011) farm gate prices of dried and locally processed *A. corrorima*

capsules is 50 to 60ETB per kg and when it come to the central market more than 30% price increase is very common. This implies that the crop has become very important and request intervention on the development of production and post harvest package and sustainable utilization and conservation. Despite of these paramount economic roles of the commodity, research conducted on this crop in particular and other spices, herbs and medicinal plants in general has been limited to very few activities.

Ethiopia is a homeland for many spices and stimulants such as *A. corrorima*, long pepper (*Piper spp*.), buckthorn (*Rhamnus prinoides*), black cumin (*Nigella sativum*), bishop's weed/Ethiopian caraway (*Trachysperspermum ammi*), coriander (*Coriandrum sativum*), sesame (*Sesamum sativum*), chat (*Catha edulis*) (Parry, 1969 cited in Edossa, 1998). As discussed by Girma *et al*. (2008), the country is a land of diverse climate and soil types that enable prolific growth of several indigenous and exotic spices, herbs, medicinal and other essential oil bearing plants. Despite the availability of diverse agro-ecologies in the country to produce many kinds of spices and the significant economical, ecological and social roles of these commodities, the research conducted on spices including *A. corrorima* is very limited. Research on spices, herbs and medicinal plants has been running since the inception of coffee research as coffee diversification. However, for some reasons, research on spices has been limited to introduce ones such as black pepper, cardamom, turmeric, ginger and cinnamon. Currently, the national spice herbs research program has also included indigenous spices in to research priority including crops such as *A. corrorima*, black pepper (*piper nigrum L*.), ginger (*Zingibere officinale* Rosc.), cardamom (*Elettaria cardamomum*), turmeric (*Curcuma domestica*), cinnamon (*Cinnamomum verum*), vanilla (*Vannila fragrance*), black cumin (*Nigella sativa*), coriander (*Coriandrum sativum*) and fenugreek (*Trigonellafoenum-graecum* L.) (EARO, 2000; Birhanu, 2010).

The spices, with their magnificent uses and potentials for the nation, have lots of challenges: no improved varieties, production packages and postharvest handling not well developed. Especially, the most important aspect of quality of *A. corrorima* is not well investigated or developed. Till present all post harvest processing practices of *A. corrorima* capsules are very traditional which automatically contributed for low quality products. As the spice is collected from the wild inside forest, the capsules are harvested mostly in mixtures of different maturity stages because of competition among wild spice

collectors and wild animal such as apes, monkeys and squirrels. Similarly, subsequent practice of drying of the capsules also varies among collectors. Often times, the quality of dried capsules is poor to the extent that moulds are developing on the surface of the capsules. Among the different drying structures being practiced, drying on bare ground, cement floor, raised beds covered with palm leaves mat, raised beds covered with wire mesh, simple mat spread on the ground and by hanging bunched capsules on cellars near fire places are some of the frequent ones. It is probable that all the existing structures may not have the same efficiency in terms of drying and extending the shelf life and, above all, in retaining the best final quality of the capsules. To date, there is no comprehensive study to identify the most quality ensuring structures of drying. In addition, if the capsules are not properly dried, or are mixed with immature ones, the end product is of poor quality (Jansen, 2002). Besides to these harvesting stages and drying structures, drying duration is another big issue which influences the quality of the final product (Girma *et al*., 2008). Standardization of harvesting stages, drying materials and durations has not been done anywhere in the world for the mere reason that the crop is native to Ethiopia and no commercial production has been started elsewhere.

In this context, it is vivid that due to inappropriate harvesting stages, drying structures and drying durations of the spice, growers/collectors in Ethiopia, even at the birth place of *A. corrorima*, are not producing quality capsules and, hence, it is assumed that there is a huge loss of income from the spice. As a mitigation strategy, it is crucial to have accurate recommendations with regard to harvesting stages, appropriate drying structures and optimum drying durations for attaining optimum quality of the spice (Eyob *et al*., 2008). These and other appropriate post harvest handling and processing methods of spices is quite imperative and can play important role in minimizing the quality related problems thereby enhancing sustainable production of spices and competitive power of the producers in the local and global market. Cognizant of this fact, the present study was focused on optimizing of harvesting stages, drying structures and drying durations of *A. corrorima* with the following objective:

- To determine appropriate harvesting stages, drying structures and drying durations for quality improvement of *A. corrorima* capsules.

2. LITERATURE REVIEW

Several important crop plants have their origin in Ethiopia, among which coffee and several crop species are cultivated in different parts of the world. However, there are also several plants that may have a potential as food, spice and/or medicine, but are yet to be known outside the local usage. *Aframomum corrorima* is one of those important spices growing in several parts of Ethiopia, but little known outside the country (Eyob, 2009). The spice is obtained from the plant's seeds (usually dried capsules) (Birhanu, 2010). As the production of *A. corrorima* is confined to only Ethiopia, there is very limited literature pertaining to research findings on, botany, ecological requirement, growth, production, harvest and post harvest handling of the crop. The available literature on this and related crops has been systematically reviewed and presented in this chapter as follows.

2.1. Botanical Description

Aframomum corrorima belongs to the family of ginger, turmeric and cardamom, *Zingiberaceae* (Jansen, 2002; Zenebe, 2004; Hymete *et al*., 2006; Girma *et al*., 2008). The genus *Aframomum* comprises about 50 species and is widely distributed in the wetter parts of tropical Africa. It is closely related to *Amomum* from tropical Asia and was formerly included in it. The differences between the two genera are not still constant and it is possible that in the future the two genera will be united again (Delin and Larsen, 2009). According to (Zenebe, 2004), *A. corrorima* recorded two more wild relatives in Ethiopia, *Aframomum polyanthum* (K. Schum) K. Schum and *Aframomum sanguineum* (K. Schum) K. Schum, both from Kafa and extending from Southern Sudan to Northern Zaire. Jansen (1981) also reported one additional wild relative of *A. corrorima*, which is a subspecies of *Aframomum puberulum*. The later three species are generally not used as spice and locally referred to as "*Yezingiro Korarima*" ("*Monkey's Korarima*"). In addition, *Aframomum zambeziacum* (Baker) K.Schum occurs in similar habitats as *A. corrorima*. The major differences of *A. zambeziacum* with *A. corrorima* are that its leaves are less aromatic upon crushing, mostly grown in less shaded areas often near marshy habitats and its inflorescences bear 25 to 50 flowers (*A. corrorima* four to six flowers) (Zenebe, 2004; Eyob *et al.,* 2008). It has also a different flavor profile from Aframomum *compactum* (Java cardamom), *Aframomum globosum* (Chinese round cardamom), and *Aframomum melegueta* (grains of paradise) and cardamom (*Elettaria cardamomum* Maton),

(Purseglove *et al*., 1981; Raghavan, 2007). Relatively, the capsules of *A. corrorima* are larger-sized and when dried are dark reddish brown, brownish black, or grayish black in color and coarsely ribbed (Appendix Figure 9). The seeds are darker and have a menthol-like taste. Different reports described the oil composition of *A. corrorima* to be qualitatively similar to that of cardamom, except for the reduced content of terpinyl acetate which is the major component of the later. *Aframomum corrorima* has 2% essential oil which has more than 70% of 1, 8-cineole (Jansen, 2002; Eyob *et al.,* 2008; Girma *et al*., 2008).

Aframomum corrorima plant consists of an underground rhizome, a pseudostem, and several broad leaves and resembles *Elettaria* species morphologically (Hymete *et al*., 2006). It is perennial, rhizomatous, aromatic herb; leafy stems growing up to a height of 1m to 2m tall (Hymete *et al*., 2006); rhizome underground, subterranean, up to 1cm in diameter, profusely branched, red-brown, covered with thin, subovate scales up to 6cm × 4cm and bearing thin, fiberous, pale brown roots. The plant has unbranched pseudostem with several distichous broad leaves, mainly formed by leaf sheaths, subterete, up to 1cm in diameter but at base usually thickened up to 3cm diameter (Delin and Larsen, 2009). New suckers are borne from their underground rhizomes to replace the old ones and to enlarge the clump (Baser and Kürkçüoglu, 2001).

Its inflorescences are four to six flowered with a shortly stalked head arising singly or two together on a peduncle, 3cm to 8cm long which arises directly from the rhizome near the base of the leafy stem and sometimes at the end of the rhizomatous runner. The peduncle is usually curved, up to 7cm long, covered by imbricate, purplish-brown, subovate scales 2.5cm × 1.5cm (Jansen, 1981; Wondyifraw, 2004). Its head is covered with imbricate, purplish-brown, ovate to square bracts up to 4.5cm in diameter; each flower is surrounded by a scarious, sub oblong bract up to 6cm × 2cm, bidentate, ciliate (Eyob *et al.,* 2007).

The flowers of *A. corrorima* are white to pale violet in color (Jansen, 1981). They are bisexual but self-sterile and zygomorphic. It has spathaceous calyx up to 4.5cm × 1cm and tubular, white to pale violet corolla, 3-lobed at apex up to 4cm × 2cm, lateral lobes ovate-oblong, up to 4cm × 2cm and dorsal lobe up to 4cm × 3cm. Labellum of the flower is obovate in outline, with a half-tubular fleshy claw up to 3cm × 1.5cm and a subovate to orbicular lobe up to 3cm × 3.5cm, thin, slightly notched, yellow at throat inside. Its

stamen is fertile, fleshy filament, slightly rounded, 6mm × 5mm, connectivum fleshy , at apex with two lateral horns 4mm long; two thecae, narrowly ellipsoid, about 11mm × 1mm. The ovary is inferior, 3-locular, style thin, terete, up to 5cm long with funnel-shaped stigma, 2mm wide, ciliate, top of ovary provided with two (sometimes more) lobed, fleshy outgrowths (probably nectaries), partly clasping the style (Jansen, 1981).

Capsules are brownish in color, have a flask-like shape, and are 3cm to 6cm long and 1.5cm to 3cm in diameter. Dried capsules are commonly sold in different markets (Hymete *et al*., 2006). Capsule is indehiscent, fleshy and sub conical berry up to 6cm × 3.5cm, usually showing three longitudinal furrows but sometimes more, shiny green when immature, turning bright red at maturity, with characteristically trilocular (three cells) containing 45 to 65 seeds each. Each flask-shaped dried capsule (ca. 3cm to 7cm long and 1.5cm to 3.5cm diameter) contains aromatic seeds with shiny brown to dark brown color, about 23mm in size, spherical shape and covered with a thin mucilaginous layer (Wondyifraw, 2004). Seeds are subglobose in outline but usually somewhat angular, 2mm to 5mm in diameter, testa finely lined, glossy brown, hilum circular, whitish, aril thin, a bit fleshy, completely covering the seed (Appendix Figure 10) (Jansen, 2002).

In many morphological features, *A. corrorima* has similarity with that of cardamom. However, they have differences in certain morphological attributes. Cardamom grows up to 4.5m with mauve-marked, orchid-like white flowers and very long, lance-shaped leaves. The leaves are distichous, long, alternate and lanceolate acuminate in shape. The flowers borne on panicles and they emerge directly from the underground stem on long floral stalks. The flower-stalk proceeds from the base of the stem and lies on the ground, with the flowers arranged in a panicle. The corolla is tubular, 3-lobed, pale green, androecium with petalloid labellum, white in color with pink or purplish veins, composed of three modified stamens with an undulated edge. There are two further rudimentary staminoides and one functional stamen (Parthasarathy *et al*., 2008). Each capsule contains about 15 to 20 aromatic, dark red brown seeds that have a mild ginger flavor attached to an axile placenta (Parthasarathy *et al*., 2008). The basic chromosome number of cardamom is x = 12 and the somatic chromosome number of 2n = 48 or 52. The cytology of *Amomum* also indicated that the diploid chromosome number of *A. subulatum* is 48; however, variability is also reported with 2n = 26, 34, 42 and 44 (Peter *et al*., 2007). Conversely, the chromosome number of *A. corrorima* is still remained unknown (Jansen, 1981).

2.2. Chemical Composition

The seeds of *A. corrorima* contain 1% to 2% of an essential oil which has a typical odor, sometimes called 'Nutmeg-cardamom' (Jansen, 1981). Steam distilled dried comminuted capsules for 8 hours produce about 3.5% pale yellow volatile oil with a flat cineolic odor (Eyob *et al*., 2007). According to Purseglove *et al*. (1981), the essential oil content of the spice is a maximum of about 4.5%. The essential oil composition of *A. corrorima* is qualitatively similar to that of the Sri Lankan and Indian cardamom essential oil except for its reduced content of α-terpinyl acetate, which is the major essential oil component of the latter (Eyob *et al*., 2007). The major component of *A. corrorima* seed is 1, 8-cineole (35% to 47%) and the monoterpene hydrocarbon content is high (30% to 40%), of which Limonene, sabinene and alpha and beta pinene are the principal components. Monoterpene alcohols comprise some 7% to 14% of the oil (Appendix Figure 11) (Girma *et al*., 2008).

The major components of dried seed and pod essential oil of *A. corrorima* were found to be 1, 8-cineole (44.3%) and (E)-nerolidol (17.2%), respectively, while 32.6% of 1, 8-cineole was recorded from dried seed. It was observed that no significant differences of major constituents analyzed from fresh and dried plant samples with only minor differences of less abundant compounds (Eyob *et al*., 2007). Generally, the seeds contain higher levels of monoterpenes, example 1, 8-cineole, sabinene, β-pinene and geraniol, accounting for 94% of the total identified compounds, in contrast to the pods with 84% of monoterpenes. (E)-nerolidol was obtained from oils of both pods (3.8%) and seeds (4.50%) (Birhanu, 2010). Baser and Kürkçüoglu (2001) further stated that water-distilled essential oils from the seeds of *A. corrorima* and *A. angustifolium* were analyzed by GC-MS. Fifty compounds were characterized representing 99.8% of the oil with 1,8-cineole (32.6%) and (E)-nerolidol (11.2%) as major constituents in the oil of *A. corrorima*.

The essential oils of the leaves, rhizomes, pods and seeds of *A. corrorima* cultivated in the highlands of Southern Ethiopia were obtained by hydro distillation. The average moisture contents were 80.53% in leaves, 90.3% in rhizomes, 88% in pods and 14.19% in seeds when analyzed from fresh samples (Eyob *et al*., 2007). In the same study, it is reported that the essential oil yield of leaves, rhizomes, pods and seeds were 0.46%, 0.69%, 0.83% and 4.3% on a w/w dry basis, respectively. Based on the GC and GC-MS analysis, there were 42 and 40 compounds in pods and seeds consisting of 95% and 99% of the total

components were identified from the essential oil obtained, respectively. The major constituents in essential oil from fresh pods were found to be γ-terpinene (27.1%), β-pinene (15.4%), α-phellandrene (8.5%), 1, 8-cineole (6.7%) and p-cymene (6.4%), whereas the seed essential oil contained 1, 8-cineole (39.3%) as the most abundant constituent followed by sabinene (10.4%) and geraniol (6.8%) (Molla *et al*., 1994). The available literature, however, does not address the difference that could arise from harvesting and processing of capsules of different maturity stages.

Besides to the similarities between *A. corrorima* and cardamom, there are differences in chemical composition of essential oil of seed and husk. According to Parthasarathy *et al*. (2008), the essential oil of cardamom seed is described as sweet, spicy, warm, lightly camphorated and citrusy. It contains about 1.5% α-pinene, 0.2% β-pinene, 2.8% sabinene, 1.6% myrcene, 0.2% α-phellandrene, 11.6% limonene, 36.3% 1, 8-cineole, 0.7% γ-terpinene, 0.5% terpinolene, 3% linalool, 2.5% linalyl acetate, 0.9% terpinen 4-ol, 2.6% α-terpineol, 31.3% α-terpinyl acetate, 0.3% citronellol, 0.5% nerd, 0.5% geraniol, 0.2% methyl eugenol and 2.7% *trans*-nerolidol (Korikanthimath *et al*., 1999). The basic cardamom aroma is produced by a combination of the major components, 1, 8-cineole and α-terpinyl acetate (Parthasarathy *et al*., 2008).

The pericarp (husk) of *A. corrorima* dried capsules which were purchased from Merkato, the largest open market in Africa, yielded 0.27% volatile oil by steam distillation method (Clevenger-type). The volatile oil was subjected to GC-MS analysis and 55 compounds were identified, constituting greater than 98% of the total oil. The major compounds characterized were sesquiterpenic structures (≥2%) such as (*E*)-nerolidol (17.2%), β-caryophyllene (9.7%) and caryophyllene oxide (6.9%) dominated in the husk oil (Hymete *et al*., 2006). As Parthasarathy *et al*. (2008) stated, the dried pericarp (husk) of large cardamom as well yielded 0.18% volatile oil by the Clevenger hydro distillation method. The volatile oil was subjected to GC-MS analysis and 37 compounds were identified, constituting greater than 98% of the total oil. The major compounds characterized were 1, 8-cineole (38.7%), β-pinene (13.6%), α-terpineol (12.6%), spathulenol (8.3%), 4-terpineol (4.5%), germacrene D (3%), α-pinene (2.8%) and β-selinene (2.7%). GC and GC-MS data revealed that the 1, 8-cineole content was less than 50% when compared with the seed oil.

2.3. Ecology

Aframomum corrorima is widely distributed in Western Ethiopia (Provinces of Kafa, Sidamo, Illubabor and Wollega), Sudan (Southwestern, Aloma Plateau), Uganda (Western) and Tanzania (Usambara Mountains) (Jansen, 1981). Although some people had hinted its existence on the Aloma Plateau of Sudan, most reports attest the spice to be endemic to Ethiopia (Wondyifraw, 2004). *Aframomum corrorima* is a shade obligate plant largely growing wild and predominantly in the Southwest montane moist evergreen forests of Kafa, Gofa, Masha and Mocha (Bench-Maji) within an altitudinal gradient of 800m to 2500m (Appendix Table 1), the optimal altitude range being 1500 to 2300 m.a.s.l. (Zenebe, 2004). According to Edossa (1998), the crop grows naturally at altitude ranging from 1000m to 2000m. Furthermore, Hymete *et al*. (2006) indicated that the crop grows naturally at 1700m to 2000m altitude in slightly shaded, moist and open woodlands, but may also be planted and cultivated being shade is obligatory. The crop is essentially a rain forest plant and thrives best near perennial water streams and in cool and constantly moist but not water logged conditions, and in areas not less than 35% shade. It is found naturally growing in the tropical rain forest regions of Southern, Southwestern and Western parts of Ethiopia in almost the same habitat as natural coffee but it tolerates a much loftier canopy and heavier shade than coffee (Zenebe, 2004; Girma *et al*., 2008). The commercial capsules are collected simply from naturally occurring under-storey (forth stratum) plants growing in association with other commercially useful shrub species such as coffee (*Coffea arabica* L.) and Ethiopian long pepper (*Piper capense* L.) (Fekadu, 2009).

The upper stratum is occupied by the primary big tree species of the genera *Podocarpus*, *Albiza*, *Cordia* etc. which utilize largest portion of the incoming sunlight. The second stratum from the top is formed by the secondary tree species of the genera *Croton*, *Bersama*, *Bridelia* etc. which are largely used for firewood, chip wood and some building materials. The third stratum is occupied by shrub species of the genera *Carrisa*, *Galineira*, *Coffea*, *Gyno-sporia*, *Piper* etc. and the forth stratum is occupied by shade-obligate species including *A. corrorima* (Zenebe, 2004).

Annual rainfall varies from 1300mm to more than 2000mm; there is no distinct dry season though most rain usually falls from June to August (50% to 60%) (Sebsebe, 1993). A

report by Zenebe (2004) also indicated that the annual rainfall varies from ca. 1200mm to 2400mm with no definite dry season. The annual average temperature is about 20°C (Jansen, 2002). According to Mesfin *et al*. (1991) cited in Zenebe (2004), the minimum and maximum annual temperature ranges from about 11°C to 12°C and 22°C to 23°C, respectively with annual relative humidity of 50% to 70%. However, this range could also be extended through cultivation, as it is confirmed from its current growth outside the tropical regions.

Aframomum corrorima grows is shade loving plant like cardamom (*Elettaria cardamomum*). Shade is very important for production of both crops since it creates suitable microclimate and regulates moisture and temperature, which facilitates optimum growth and root development particularly when *A. corrorima* rhizomes produce very shallow roots at each node (Birhanu, 2010). Therefore management and maintenance of the optimum level of shade is one of the key agronomic practices in *A. corrorima* production. In fact, shade level of 55% to 63% has been reported as optimum (Zenebe, 2004; Girma *et al*., 2008; Birhanu, 2010).

According to Zenebe (2004), *A. corrorima* generally grows on sloping land of different gradients. The topography in its natural habitat is generally hilly with a well-drained, dark-brown or red clay soils, which is naturally rich in humus with a pH range of 4.5 to 7 (Appendix Table 1). The crop has similar climatic and soil requirement with large cardamom (*Amomum subulatum*) and small cardamom (*Elettaria cardamomum*). Deep and well drained forest soils with a loamy texture are best suited for large cardamom. A soil rich in organic matter and nitrogen, medium in available phosphorus, medium to high in available potash, pH range of 4.5 to 6 and land with a more moderate slope is suitable for the crop (Pathak, 2007). Similarly, small cardamom generally grows well in forest loamy soils that are acidic in nature, high in organic matter and nitrogen, low to medium in available phosphorous and medium to high in available potassium and pH range of 5.5 to 6.5 is preferable for the crop (Spices Board of India, 2009). According to this context, *A. corrorima* may also respond better in those soils which are favourable for large and small cardamoms.

2.4. Importance

Aframomum corrorima is one of the few under-exploited plant species with promising economic value in Ethiopia. It is an important cash crop which grows abundantly in the natural forests of Southern, Southwestern and Western parts of the country where coffee grows. The spice has been part of each and daily Ethiopian dish in preparation of curry powder for culinary purpose. The seeds are used to flavor all kinds of "*wot"*, for which they are ground and usually mixed with other spices, to flavor coffee, sometimes tea and bread (Eyob *et al*., 2008; Girma *et al*., 2008). With regard to medicinal attributes, *A. corrorima* seeds are used medicinally in Ethiopia as carminative, tonic agent, purgative as well as laxative (Wondyifraw, 2004; Hymete *et al*., 2006).

Another widespread use of the seeds in Ethiopia is for flavoring of coffee. The people in Southwestern Ethiopia use it commonly for flavoring of coffee prepared from coffee leaves. Sometimes the seeds are used to flavor a special kind of bread. Butter is also flavored with *A. corrorima* in Ethiopia. It was also mentioned that the capsule had been used as money for barter on older times (Eyob *et al*., 2008; Girma *et al*., 2008).

Similarly, cardamom is used as aromatic, carminative, stimulant and as a flavoring agent in tea and food preparations. Though no investigation is done for *A. corrorima,* cardamom is also used internally for indigestion, nausea, vomiting and pulmonary disease with copious phlegm and also as a laxative to prevent stomach pain and griping, as well as flatulence. The seeds of cardamom have a warm, slightly pungent aromatic flavor and chewed to sweeten the breath and taken to detoxify caffeine in people drinking excessive amounts of coffee. In India, it is used for many conditions, including asthma, bronchitis, kidney stones, anorexia and general debility, as well as for disorders of the urinary tract. It is also used for digestive upsets, soothing a spastic colon and relieving flatulence and constipation (Parthasarathy *et al*., 2008).

2.5. Production, International Trade and Utilization

The most important spices traditionally traded throughout the world are products of tropical environments. The major exceptions to this group are the capsicums (chilli, peppers and paprika) and coriander which are grown over a much wider range of tropical

and non-tropical environments (UNIDO and FAO, 2005). According to Peter (2004), the global spice trade is expected to increase with the growing consumer demand in importing countries for more exotic, ethnic tastes in food. About 85% of spices are traded internationally in whole form, with importing countries processing and packaging the final product for the food industry and the retail market (Peter, 2001). The trade in processed and value-added spice ingredients is, however, growing rapidly as importers look for cheaper global sourcing of spice products and exporting businesses develop the appropriate technologies and quality systems. The European and American markets are the major consumers of herbs and spices (Peter, 2004). The USA is the biggest importer of spice products, followed by Germany, Japan, Singapore, Saudi Arabia and Malaysia (Peter, 2001; Birhanu, 2010). The European Union has the largest imports of spices in value terms, worth USD 2.20 billion (Peter, 2004).

The principal spice supplying countries are China, India, Madagascar, Indonesia, Vietnam, Brazil, Spain, Guatemala and Sri Lanka (Parthasarathy *et al*., 2008; Birhanu, 2010). Egypt, Turkey, Spain and Albania are also the major exporters of herbs and spices (Peter, 2004). During the period from 2000 to 2004, the value of spice imports increased by an average of 1.90% per year and the volume increased by 5.9%. World trade in spices in 2004 consisted of 1.55 million tons, valued at USD 2.97 billion. An annual average rate of 7% increase was seen in the global import volume of spices in the period 2000 to 2002 (Birhanu, 2010).

In Ethiopian context, the cultivation of spice is predominantly stayed traditional for centuries by small scale land holding farmers. Recently the average land covering by spices has been 222,700 hectares and the production reached 244,000 ton per annum. The seed spices potential areas are Amhara and Oromia regions while for the low land spices dominantly produced and potential in SNNP and Gambela regions. In general the total potential for the low land spices is estimated to be 200,000 hectare (Edossa, 1998).

According to Chanyalew (1999) cited in Wondyifraw and Surawit (2004), starting few years ago, great fluctuation of price and instability of supply of *A. corrorima* became a common happening. This condition is mainly due to reduction of production as a result of destruction of the natural habitat of the plant (Birhanu, 2010). Compared to cardamom, it has relatively wider adaptation and higher yield (ca. of 5.5-fold). Although no statistics are

available, the amount of capsules (the seeds are sold per capsule) offered for sale in Ethiopia is considerable. It is present at every market, and is sold for a high price compared to other spices. Besides the large domestic consumption of the spice, Ethiopia exported it to Sweden, Finland, Sudan, India, Egypt and Saudi Arabia. Export to Europe and the United States is very small, mainly due to the product often being of poor quality (Jansen, 1981). The capsules are mostly harvested from wild. Previously, the crop had notably penetrated the Scandinavian market and was priced at 9USD per kg in early 1978 as a substitute for Indian cardamom (Birhanu, 2010).

A number of developing countries mainly in Asia have developed technologies to export various extracts as value added (Essential Oils and Oleoresin) commodities based on indigenous spices. They also recognized that there are quite a number of spices in Ethiopia including *A. corrorima* that could be used for this purpose. Currently, there are only two spice extraction factories in the country: Ethiopian Spice Extraction Factory and Kassk Spices and Herbs Extraction PLC. These extracting factories are presently not operating at full capacity due to machinery obsolescence and shortage of raw materials (Ethiopian Investment Agency, 2010). However, since there is vast area of suitable land for the production of spices in the country, it is possible to increase spice production and this may be taken as an opportunity for recognizing both the domestication and promotion of in situ production for commercial purposes (Zenebe, 2004).

2.6. Marketing and Quality Standards

Marketing is an insurmountable problem besetting the development of the spice industry in developing countries. The prices are dictated by the buyers who control the market leading to unreliability and low prices. As a result the poor producers have suffered and even abandoned the production of spices in favor of other crops (Rukangira, 2001; Raghavan, 2007).

Control of the quality of raw materials, finished products and of processes is an absolute necessity, if one is to produce goods for world markets and human consumption. Among the main constraints hampering the development of the spice sector is the difficulty faced by the spice farmers to enter into the world market which is dictated by global competition (ITC, 2010). Marketability of spices is a crucial factor in determining the failure or

success of industries. Information on market prices and demand is difficult to get in view of the protective nature and limitations of the market. Furthermore the market is characterized by price fluctuations and high competition and substitute synthetic products. As such in the first instance, it may be useful to conduct market studies on local demand rather than the export potential (Silva, 1995). In developing countries, essential oils can be produced for import substitution resulting in saving the much limited foreign exchange. Some products could reach the consumer directly while others have to be either further processed or used as additives in other industries. Hence, user industries have to be promoted so that the locally produced essential oils can be used as substitutes for the imported additives. Further processing to yield value added products will be limited by the local demand situation unless they could be produced at prices to be competitive in the world market. Even if the cost of production is low and quality of the products are good, aggressive market promotion has to be undertaken in order to penetrate the world market (Silva, 1995; Stoep, 2010).

Having recognized the magnitude of enhancing the export of raw materials and/or processed products produced in developing countries, assistance has been rendered by providing expert advice on the assessment of market data, including the chain in demand and supply situation, price trends, most feasible types and qualities of essential oils, that could be marketed, identifying different marketing arrangements and important trading houses, and recommending short-term and long-term strategies for export promotion (Silva, 1995).

In the last decades, Ethiopia had been well known for its substantial exports of *A. corrorima* capsules to different parts of the world. However, currently the supply has been greatly fluctuated and changed. In the early 70's, an average of 118 and 11 tons of dried capsules were manually exported to Sweden and Finland, respectively (Wondyifraw, 2004). During the past few decades the total annual *A. corrorima* export has decreased to less than 60 metric tons in the years 1994 to 1998, fetching only some 2.10 million USD (Jansen, 1981). In the year 2001, there was a very serious shortage of *A. corrorima* supply in the market and the price as high as 23.5USD per kg. This condition is mainly due to reduction of production as a result of destruction of the natural habitat of the plant due to the expansion of arable land and grazing land, urbanization and bush fire. Therefore, the current irreversible destruction of their natural habitat is even threatening the mere

existence of the crop in the country. Besides, there are no visible activities regarding establishment of new plantations (Birhanu, 2010).

2.6.1. Quality

The term quality may be defined as “the degree of excellence, relative nature or kind of character, class or grade of thing as determined by this, general excellence". A more appropriate term is quality which can be defined in the case of herbs and spices as ‘fit’ for the purpose intended (Peter, 2001; Peter, 2004; Raghavan, 2007). Quality of spices is mainly assessed by its intrinsic and extrinsic characters. The intrinsic characters consists of chemical quality, which is the retention of chemical principles basically essential oil, alkaloids and oleoresins while the extrinsic characters emphasizes physical quality mainly appearance, texture, shape, presence or absence of unwanted things and color. In addition, certain health requirements should also be implemented as export quality standard that is pesticide residue, heavy metals, sulfur dioxide, solvent residues and microbiological quality. However, physicochemical quality remains the ultimate attribute, while considering export requirement of spices as these properties delineate its grade in the market. These qualities vary unpredictably. The physicochemical characteristics vary widely depending on the variety, agro-climatic conditions existing in the area of production, harvest and post harvest operations (Jose and Joy, 2004).

Herbs and spices have traditionally been traded as dried products for reasons of appropriate preservation. The industry goes back before the time of Christ when drying was one of the main forms of food preservation. Drying was then by means of the sun and this method is still widely used in most developing countries. With the advent of modern transport methods and methods of processing and preservation, frozen herbs, fresh herbs and spices have made an appearance as items of trade, but the industry remains dominated by the trade in dried products. The major quality specifications set are based mainly on dried herbs and spices (Peter, 2001).

2.6.2. Major quality specifications of spices

Herbs and particularly spices have always been highly-priced commodities and vulnerable to adulteration. In consequence simple standards were evolved early. Today the two major

international standards are those set by the United States and those set by the European Union (EU) (Peter, 2001). Standards relying on the same general parameters also exist in those countries responsible for growing herbs and spices, for example the Indian Spices Board and the Pepper Marketing Board. These standards are influenced by those set by the major importing countries. There are various types of test which make up the range of international standards (George *et al*., 2007).

Total ash content: Total Ash content is a measure of the total amount of minerals present within a food. It can also be defined as the inorganic residue remaining after the water and organic matter have been removed by heating. Analytical techniques for providing information about the total mineral content are based on the fact that the minerals can be distinguished from all the other components within a food in some measurable way (ESA, 2004). The most widely used methods are based on the fact that minerals are not destroyed by heating, and that they have a low volatility compared to other food components. The three main types of analytical procedure used to determine the ash content of foods are based on this principle: dry ashing, wet ashing and low temperature plasma dry ashing. The method chosen for a particular analysis depends on the reason for carrying out the analysis, the type of food analyzed and the equipment available (Peter, 2004). Ashing may also be used as the first step in preparing samples for analysis of specific minerals, by atomic spectroscopy. Ash contents of fresh foods rarely exceed 5%, although some processed foods can have ash contents as high as 12%, *e.g.,* dried beef (Kizhakkayil *et al*., 2006). Furthermore, total ash content refers to the measure of the level of impurities in a product, obtained by burning off the organic matter and measuring the residue of ash. This measurement is carried out by incinerating the herb or spice at 550ºC to constant weight (Peter, 2001).

Oleoresin (non-volatiles and volatiles): The term oleoresin is used for the natural exudate which is rich in essential oils; however, it is also used in the seasonings, flavor, and food industries to describe the solvent extractable of spices and herbs from which the solvent has been removed. Spice/herb oleoresins contain, not only the essential oil of the original plant material, but also the fixed or vegetable oil, the color, and the active principles, although their composition is solvent specific (Silva *et al*., 2005). It is produced by grinding or crushing the spices, extracting with solvent (acetone, ethylene dichloride,

hexane, isopropyl alcohol, methyl alcohol, methylene chloride, and trichloroethylene) by Soxhlet apparatus and then removing the solvent (Silva *et al*., 2005; Raghavan, 2007). It represents the complete flavor and non-volatile resinous fraction present in a particular spice (Peter, 2001). Oleoresin has the full flavor, aroma and pungency of fresh or dried spices because they contain the high boiling volatiles and non-volatiles, including resins and gums that are native to spices. The non-volatile components create the heat and or pungency of a particular spice (Raghavan, 2007). These components can be acid-amides, such as capsaicin in red pepper or piperine in black pepper, isothiocyanates in mustard, carbonyls such as gingerol in ginger, and thioethers such as the diallyl sulfides in garlic or onion (Peter, 2004).

Essential oil: Essential oil is volatile, fragrant oils that occur in plants and in general contribute to their characteristic odors, flavors, or other such properties. Studies have revealed that there is a spectrum of essential oil present in *zingibereaceae* species, which is used widely as spice, flavoring and medicinal sources. It is found in various parts of the plant body such as seeds, flower petals, bark, rhizomes, roots and leaves. Essential oil is also concentrated in certain special groups of cells (Kung, 2008). It is the major flavoring constituents of a spice (Peter, 2004) with many chemical components, sometimes even up to fifteen, but the characterizing aroma generally constitutes anywhere from 60% to 80% of the total oil (Raghavan, 2007). It is a mixture of various aroma chemicals, basically monoterpenes, sesquiterpenes and their oxygenated derivatives, having a boiling point ranging from 150°C to 300°C (ICS-UNIDO, 2008).

Essential oil measure helps to identify whether the herb or spice has been adulterated, perhaps by addition of foreign materials, low quality or spent amounts of the herb or spice in question (Peter, 2001). The herb or spice is boiled under reflux conditions with water where the oil separates on top of the water and can be read off in a volume proportional to the mass of the product under test essential oils are produced by grinding or crushing of the plant part and then extracting through steam distillation (using water, steam, or steam and water) and recovering the distillated oil (Tainter and Grenis, 2001). Depending upon the method of extraction, the nature of the volatiles can differ with the same type of spice (Raghavan, 2007).

Moisture content: Moisture content measure is important since it determines storage, weight, and weight is used in pricing. With highly priced commodities traded on weight, a 1% moisture increase in the product as shipped can result in increased weight and increased profits for the original exporter. Maximum moisture contents are set for all herbs and spices, based on the maximum allowable amount of moisture for the product to remain stable. Moisture content is generally determined within the herb and spice industry using the Dean and Stark methodology. This involves re-fluxing a known weight of the herb or spice in petroleum spirit and measuring the water that condenses at the bottom of the reflux chamber from the known weight of herb or spice. Generally the level is 12% max (Peter, 2001). Fresh cardamom capsules generally contain 80% to 85% (wet basis) moisture (Karansinh, 2002). It is essential that the moisture level of the spice to be stored should be at safe level prior to storage (UNIDO and FAO, 2005). Moisture content should not be more than 12% for preventing fungal infection and long period storage (George *et al*., 2007).

Crude fiber content: This is the loss on ignition of the oven dried residue remaining after sequential digestion of a sample with H_2SO_4 and NaOH solutions under specific conditions. In other words it is an insoluble fiber found in many foods, which mainly consists of lignin which is found in plants (George *et al*., 2007).

Crude fiber is an insoluble fiber found in many foods. It mainly consists of lignin which is found in plants. Humans need crude fiber to help with maintaining regular bowel movements. Crude fiber is the loss on ignition of the oven dried residue remaining after sequential digestion of a sample with H_2SO_4 and NaOH solutions under specific conditions (Raghavan, 2007).

The compounds removed through sequential digestion with sulfuric acid and sodium hydroxide solutions are predominantly protein, sugar, starch, lipids and portions of both the structural carbohydrates and lignin. These residues (containing cellulose, hemicellulose, lignin, ash and tannins) are indigestible substances, often called structural carbohydrates, and are characterized by low or no nutritional value (Peter, 2001).

Mesh/particle size: Many spices and herbs are ground to give easier dispersion in the final food product. This process also aids the dispersion of flavor. Particle size is generally

specified and is carried out using standardized sieves. Aperture sizes give a particle size, the products being ground to pass a certain sieve, and coarse matter recycled through the mill until it finally passes through the sieve. Sieves are characterized in micron sizes and typical requirements will be a 95% pass on a specified size of sieve. The older method of measuring sieve sizes was that of mesh which related to the number of holes per inch. However, confusing differences exist between American and British mesh sizes. The mesh size (number of holes per inch) depends on the diameter of the wire making up the sieves and this differs between nations. Thus a 25 mesh US sieve is equivalent to a 30 mesh UK sieve and both are equivalent to a 500 micron aperture size (Peter, 2001).

2.6.3. Rules and regulations monitoring hygienic quality

There is no specific standard prescribed for *A. corrorima* by Codex Alimentarius Commission and it goes with any other food produce. But, the International Standards Organization, Geneva has drawn up the International Standards in 1997 with number ISO 10622 1997 (E) for large cardamom (George *et al*., 2007). The standard prescribes four chemical requirements namely, moisture 12% maximum, Volatile oil 1% minimum, total ash 8% maximum and acid insoluble ash 2% maximum both for capsules and seeds (George *et al*., 2007). According to George *et al*. (2007), there is a proposal now to revise the standard prescribing separate specifications for capsules and seeds.

Capsules of large cardamom should have extraneous matter not more than 5% by weight, insect damaged capsules not more than 5% by weight, moisture not more than 14% by weight, volatile oil ml/100g (%) not less than 1.5% by weight and free from visible mould and insects while seeds of large cardamom should have moisture not more than 13% by weight, volatile oil not less than 2% by weight, total ash not more than 5% by weight, acid insoluble ash not more than 2% by weight, extraneous matter not more than 2% by weight, insect damaged seeds not more than 2% by weight, color and flavor Natural and characteristic and free from moulds and insects (George *et al*., 2007). Usually *A. corrorima* goes with large cardamom in particular and all cardamoms in general. Thus, standard prescribing separate specifications for large cardamom may more likely work for *A. corrorima* capsules and seeds.

2.6.4. Factors Affecting Quality of *A. corrorima*

Quality has to be built into the whole process of production beginning from selection of propagation material to the final product reaching the consumer. It is therefore a management system where all steps involved in the utilization process have to be properly and strictly controlled to produce the desired quality products. Control of the quality of raw materials, finished products and of processes is an absolute necessity, to produce goods for global markets. Monographs have to be prepared for each product to include all the specifications developed. Modern analytical techniques can be extensively used to develop identity, purity and quality parameters. The machinery and processes used in industries have to be validated to comply with International Standards. It is imperative that the processed products comply with International Standard Specifications (ISO) for most of the essential oils. In addition, countries and buyers can have their own requirements (Silva *et al*., 2005).

As far as known, there is very limited literature pertaining to research findings on post harvest handling and quality of the crop. The literature available on factors influencing quality and yield of *A. corrorima* is very scanty or almost no, but *A. corrorima* capsules respond in similar manner in most cases with large cardamom and/or small cardamom except the magnitude of the quality parameters. Thus, partly, the literatures on the quality issues of *A. corrorima* capsules are in line with the quality issues of large cardamom and/or small cardamom capsules in particular and spices in general.

2.6.4.1. Harvesting and stages of harvesting

Harvesting is the first step of postharvest operations. It is the primary process of collecting the target crop product from the field, where it is open to the vagaries of the climate and the growing environment, and placing that product in controlled processing and stable storage conditions. Harvesting of spices is a complex matter and is dependent upon the local conditions, whether they are climatic conditions, soil conditions or variability in varieties available. The harvesting requirements will differ for the final product sought, and there are specific needs such as maturity and evenness that will dictate the harvesting management and timing. Stage at which the fruits are harvested is the mature or more scientifically, physiologically mature condition, but not ripe. Plant parts are better to be

harvested under the best conditions; avoiding dew, rain or exceptionally high humidity (UNIDO and FAO, 2005).

Harvesting stage at maturity of most spices is the governing factor influencing quality next to the type of variety/cultivar produced (Purseglove *et al*., 1981). Also in Ethiopia environment, stage of maturity of ginger at harvest (Girma *et al*., 2009a), black pepper (Girma *et al*., 2009b) significantly affected quality of the products. In that, it is not possible to produce good spice product from low quality harvested material. The main obstacle to correct harvesting is the crop being picked immature. Small immature capsules bring about uneven shriveled and undesirable color after processing. Thus, harvesting at correct maturity stage is a pre-requisite for improving the quality of the produce (Spices Board of India, 2009). The harvesting requirements will differ for the final product sought, and there are specific needs such as maturity and evenness, that will dictate the harvesting management and timing. Capsules should be harvested when they attain physiological maturity to fully ripened stage as to allow the capsules for the proper seed development and to obtain higher recovery. For instance, in the case of small cardamom, recovery is highest (29%) in the fully ripened capsules followed by the one harvested at physiological maturity (24%) and in immature stage (14%) (Zachariah and Korikanthimath, 2002). Plant parts are better to be harvested under the best conditions; avoiding dew, rain or exceptionally high humidity (UNIDO and FAO, 2005). Due to the prolonged flowering period and its irregular nature, *A. corrorima* capsules ripen successively at intervals over an extended period, necessitating several pickings (Girma *et al*., 2008).

Plant materials should be harvested during the optimal season or time period to ensure the production of plant materials and finished spice products of the best possible quality. The time and stage of harvest depends on the plant part to be harvested and intended for. In case of coriander (*Coriandrum sativum*) for example, the volatile oil content of the fruit reaches maximum while it is still mature unripe and during ripening; it diminishes owing to a collapse of the peripheral volatile oil canals. However, since the volatile oil present in the peripheral canals imparts a rather fetid, bedbug-like odor to the fruit, harvesting is delayed until the fruit has ripened and the characteristic, sweet odor of the spice has developed (Parthasarathy *et al*., 2008). In cardamom too, essential oil content is 20% to 30% more in the physiologically mature stages compared to ripe stage (Zachariah and Korikanthimath, 2002).

Soil can have high microbial content and contact with the harvested crop. Thus, the soil should be avoided so as to minimize the microbial load on the harvested plant materials. Large drop cloths preferably made of clean muslin, where necessary, should be placed on the soil surface before the plants are harvested. If underground parts such as rhizomes are harvested, any adhering soil should be removed as soon as possible (UNIDO and FAO, 2005).

Aframomum corrorima is an indigenous spice crop of Ethiopia, with hardly tangible work done in the areas of harvesting, harvesting stages, processing and market preparation structures and techniques. Its flowers and red ripe capsules can be found at the same time in the field due to the irregularity of flowering. Harvesting time of *A. corrorima* varies in different areas of Ethiopia but generally the plant flowers from May to August and harvesting starts from August to September and stay up to January, October and November being the peak harvest months (Girma *et al*., 2008). On the other hand, Hymete *et al*. (2006) reported that the plant flowers from January to September and the fruits mature about 60 to 90 days later in. At the early stage, the color of capsules is green that later turns to half red and finally to dark deep red color as it matures and gets ready for harvest (Girma *et al*., 2008). Although there appears to no comprehensive study with regard to the effect of harvesting *A. corrorima* capsules at different stages, it is believed that in order to get quality product, the capsules should be red ripe and the seeds when removed from the capsule should be dark brown that have pungent and appreciable taste when crushed by teeth. There should also be great care while harvesting the capsules not to create any opening on the capsules that could lead to loss of important quality components (aroma and flavour) and serve as entrance for micro organisms (Birhanu, 2010). The capsules are picked manually when they are red ripe and seeds turn blackish or brownish. The first harvest starts 2 to 3 years (clonally propagated) and 3 to 4 years (generatively propagated) after planting depending on the locality in which the crop is grown (Zenebe, 2004). However, collectors from the forest have no patience to wait for the capsules to get fully red as they have no grantee that it will be there as they come back next time to the same spot; either another collector or a wild animal (usually monkeys) have already picked it.

2.6.4.2. Pre-drying treatment

Harvested capsules contained lot of impurities such as soil, dirt and other unwanted plant parts. Thus, immediately after harvesting, thorough washing of capsules with clean running tap water is recommendable to eliminate these impurities (Zachariah and Korikanthimath, 2002). Washed capsules are allowed to drain water for some time. Washing should be done in rooms devoid of direct sunlight (UNIDO and FAO, 2005). Chemical treatment may also apply in such a way that capsules after washing may soaked in 2% washing soda (Na_2CO_3) solution for 10 minutes (BeeHive Digital Concepts Cochin, 2006). But in case of *A. corrorima*, there is no great consideration for such activities. From observation, the collectors simply harvest more at mature green stage and they were not go for washing or any treatment of the fresh capsules which more likely contribute to poor quality of capsules as contamination and fungal infection may be high.

2.6.4.3. Drying

This is by far the most important stage in the process and production to ensure good quality dried spices (UNIDO and FAO, 2005). Inadequately dried produce will lead to mould growth. Whichever stage the *A. corrorima* capsules are harvested from natural forests; they are processed or dried in traditional ways. According to a survey conducted by Jimma Research Center in 1990/91, the series of activities carried out by farmers in the preparation of *A. corrorima* passes two steps before it reaches the market: (1) pre-drying: harvested capsules are stored in a warm place covered with straws, enset leaf or other materials for 10 to 15 days and (2) drying: performed in two ways (a) sun drying: capsules are spread on clean ground or on materials prepared for this purpose. Drying in this way, take 10 to 15 days depending on the length of sunny hours and the intensity of sunlight. (b) Drying with smoke: This involves spreading of the capsules on a wooden bed over chimneys under the roof for 15 to 20 days. In some cases both methods could be employed depending on the weather condition (Girma *et al*., 2008; Birhanu, 2010). However, to date there is no study conducted to assess the impact of different structures and durations of drying the capsules on quality.

Yield generally increases in subsequent years until it gets to a maximum in 6 to 7 years after planting. It can vary from 700kg to 1200kg of dried capsules per hectare (Zenebe,

2004; Girma *et al*., 2008). Jansen (1981) also mentioned that the yield can be as much as 500kg of dried capsules per hectare without fertilizer application. Mature capsules are usually sun dried and sold, although occasionally sold as seed. The capsules are dark brown in color when dried, measuring between about 3cm to 5.6cm in length and about 1.5cm to 2.6cm in diameter (Purseglove *et al*., 1981). A dried capsule usually has a hole in the shell owing to the drying on string. Experiments from Jimma Agricultural Research Center indicated that there is normally 60% to 65% reduction in fresh weight when capsules are dried to a moisture content of 12% (Zenebe, 2004). Capsules have a thick fleshy husk, which constitute nearly two third of weight of the total fruit. Consequently, sun drying takes relatively long time, about a month. To this effect and as a result of the unimproved drying techniques marketable capsules are usually observed discolored, blemished and at times mouldy. This indicates that with the development of better drying and post harvest handling, the potential use of *A. corrorima* both in the local and export markets could be improved (Zenebe, 2004).

2.6.4.4. Cleaning

Dried *A. corrorima* capsules require cleaning to remove all stalks and dried remains of floral parts. This may be done by rubbing dried capsules over a coarse surface of wire-mesh or bamboo trays (Peter, 2001). Cleaning the spice prior to packaging and sale is to ensure that the spice is of the highest quality and will obtain the highest price. Cleaning should remove all the foreign matter that lowers the quality and endangers the sale. Sieves, grading tables, flotation tanks and screens can all be used to ensure that the quality standards are met and an even line of high quality spice is obtained (UNIDO and FAO, 2005). From observation, the collectors of *A. corrorima* capsules simply use ground surface or mat for cleaning which may contribute to poor quality of capsules as contamination is high.

2.6.4.5. Grading

Quality requirement of a produce varies with the primary raw material producer, intermediary collector, trader, exporter, importer, processor, distributor and final consumer. Product quality is related to moisture level, cleanliness, content of substandard product, extraneous matter, appearance and color. The processor values the extractives, essential oil, oleoresin and specific ingredients based on certain specifications.

Specifications are restricted to attributes, which can be simply and rapidly analyzed. Many of them related to physical parameters such as color, size, weight per specified volume, freedom from microbial, insect and filth contaminations (Zachariah and Korikanthimath, 2002).

Aframomum corrorima is a high value crop and all care should be given for efficient processing and grading. It is essential to sort out splits, thrips and borer-infested capsules separately. Sorting out is always done by skilled women laborers. As cardamom harvest alone requires nearly 60% of total laborers (Zachariah and Korikanthimath, 2002), *Aframomum corrorima* may too, there may be a need to fabricate mechanical sorting machines so as to get different sizes with a provision to separate out capsules infested with insect and splits. Equilibrium relative humidity studies have shown that cardamom dried and maintained at or below 10% moisture avoids mould growth. If black polyethylene is used, the effect of light is further minimized and safe storage is possible for about 4 months, required for port storage and transshipment (Zachariah and Korikanthimath, 2002).

2.6.4.6. Packaging

Processed plant materials should be packaged as quickly as possible to prevent deterioration of the product and as a protection against exposure to pest attacks and other sources of contamination (UNIDO and FAO, 2005). The main tasks for packaging are to protect the spice from the external conditions and to increase the stability against negative internal changes (enzymatic and non-enzymatic chemical reactions) (Peter, 2004). Continuous in-process quality control measures should be implemented to eliminate substandard materials, contaminants and foreign matter prior to and during the final stages of packaging retaining color, flavor and expressive characteristic of the product (UNIDO and FAO, 2005; Raghavan, 2007).

Processed plant materials should be packaged in clean, dry boxes, sacks, bags or other containers in accordance with standard operating procedures and national and/or regional regulations of the producer and the end-user countries (UNIDO and FAO, 2005). The packaging must not be a source of contamination and it should be food grade and must protect the product quality during transportation and storage (ESA, 2004). However, there

is no specialized packaging and handling systems prevailing for *A. corrorima* storage. It is packed in sacks with capacity of 50kg to 100kg. Materials used for packaging are not upon agreement between suppliers and buyers. The packaging materials; sacks are usually not disinfected and thoroughly dried prior to reuse so as to avoid contamination by previous contents.

Packaging materials should generally consists of a label which clearly indicates detail of the product name of the spice, plant name, place of production, harvest date, names of the grower and the processor and quantitative information (UNIDO and FAO, 2005). The label should also contain information indicating quality approval comply with other national and/or regional labeling requirements (IOSTA, 2008). Additional information about the production and quality of the plant materials may be added in a separate certificate which is clearly linked to the package carrying the same batch number (FBC, 2008). Records should be kept of batch packaging and should include the product name, place of origin, batch number, weight, assignment number and date. They should be retained for a period of three years or as required by national and regional authorities (UNIDO and FAO, 2005).

2.6.4.7. Transport and storage

The harvested raw plant material of the spice crop should be transported promptly in clean and dry conditions. The crop may be placed in clean baskets, dry sacks, trailers, hoppers or other well-aerated containers and carried to a central point for transport to the processing facility. All containers used at harvest should be kept clean and free from contamination by previously harvested plant products and other foreign matter. If plastic containers are used, particular attention should be paid to any possible retention of moisture that could lead to the growth of mould (UNIDO and FAO, 2005). But in the case of *A. corrorima*, there is no great consideration for drying conditions, protection from insects, rodents, birds and other pests, and accessible to livestock and domestic animals. Backpack and equid are usually used for transporting of the fresh capsules from the place of production/forests to processing and storage. Bulk transport of dried capsules, such as cars, are not appropriate and not well ventilated to remove moisture from plant materials and loaded along with other materials.

Spices deteriorate rapidly in adverse conditions and should be stored in well-prepared and maintained storage facilities (UNIDO and FAO, 2005). A key issue in storage of spices is maintaining the right level of moisture (Purseglove, *et al*., 1981). The properly dried capsules should be allowed to cool and then packed in polythene lined Jute bags (Pathak, 2007). The moisture content of capsules has to be brought down to 12% to 14% to achieve a longer shelf-life (Peter, 2001). For efficient retention of quality during storage, capsules should be dried down to a moisture level of 10% to 12% (Spices Board India, 2009). Fully dried capsules tend to split and also loss its natural taste to some extent whereas excessive moisture reduces its value. A report by CFTRI (1994) cited in Peter (2001) stated that large cardamom stored over a period of six months tend to loss 4% to 20% by weight. Insect infestation also reduced the volatile oil content from 2.99% to 1.00%, particularly as a moisture content of 13% to 15% was found conducive for insect breeding (Peter, 2001). CFTRI has recommended the use of fumigants like methyl bromide (CH_3Br) (16g/m^3), phosphine (H_3P) (1.5g/m^3) and ethyl formate ($C_3H_6O_2$) (300g/m^3) to control all the stages of insect infestation without affecting the quality. CFTRI also recommended the usage of hessian cloth over wrapping of bags, in order to avoid the possibility of direct contamination of the products with the pesticides.

Plastic lined jute bag is the common storage choice. Some farmers/collectors suggest double lined plastic bags for storage. In all cases color of the lining is black. In the storehouse capsule bags are kept in airtight wooden boxes (Pathak, 2007). Some feel that the temperature must be adjusted to 30°C inside the storage room with no humidity. Storage of cardamom in wooden boxes lined with woolen blankets is also practiced in Kerala. Fungal patches may appear upon storage due to improper drying especially during the rainy season. In general storage life is influenced by the method of drying (BeeHive Digital Concepts Cochin, 2006).

In all spices and aromatic plants, the content and quality of essential oil in seeds is strongly dependent on storage conditions (Peter, 2001). On long storage, they become darker in color and highly viscous. This deterioration in quality of the oil is attributed to a number of chemical reactions such as oxidation, resinification, polymerization, hydrolysis of esters and interaction of functional groups. These processes are activated by heat, presence of oxygen or air, moisture, light in some cases and possibly by metals. The high terpene containing oils like citrus, pine needle and turpentine are particularly prone to

spoilage by oxidation and resinification. Essential oils containing high percentage of esters turn acidic after improper storage due to partial hydrolysis of esters. Alcohol containing essential oils like sandal and geranium are quite stable and withstand prolonged storage. Others like patchouli and vetiver improve considerably on aging hence are made to age before use in perfume compounds (Joy *et al*., 2005).

To prevent this, they should be stored in a cool and dry place in tightly stoppered amber glass bottles. Exclusion of air by completely filling the container with oil prolongs its storage life. Essential oils should be freed from metallic impurities and moisture followed by its clarification. Then they should be stored in well filled, tightly closed containers at low temperatures and protected from light. Bottles of hard and dark colored glass are well suitable for small quantities while aluminum containers or metal drums with tin lining used for large quantities. A stream of carbon dioxide or nitrogen gas blown inside the container before it is sealed will replace the air above the oil and thereby assure added protection against oxidation. Prior to storing, the oil should be carefully clarified and any moisture should be removed. Smaller lots can be dehydrated with the help of anhydrous sodium sulfate (Na_2SO_4). After the addition of anhydrous sodium sulfate, the container is shaken thoroughly, kept aside for 24 hours and filtered. Calcium chloride ($CaCl_2$) must never be used for dehydration as this forms complex salts with certain alcohols. Large commercial lots are not always easy to clarify. To viscous oil lots, sufficient quantity of common salt should be added and the mixture stirred for a while and allowed to stand until the supernatant oil has become clear which is drawn off. The lower cloudy layer is filtered clear. If filtration through plain filter paper does not give clear oil then kieselghur or specially prepared filtering clay should be used. Bulk lots of oil may be filtered through filter presses. Centrifuging in high speed centrifuges at more than 15,000rpm is an excellent means of clarifying essential oils. It helps to remove not only moisture but also waxy materials in the oil. High phenol containing essential oils like those of cloves and bay, when freshly distilled are in crude form and are dark colored due to the presence of metallic impurities. To get rid of these, sufficient quantity of tartaric acid powder is added to the oil lot and stirred to settle the same (Joy *et al*., 2005).

2.6.4.8. Marketing

Marketing of *A. corrorima* is disorganized to a great extent as most of the producing areas are remote. Buyers are not available within the vicinity and farmers have to carry the produce long distances. In need of money some farmers still take advances from the local village merchants and settle the loan with interest by selling the produce to them. In both situations, farmers often do not realize the real value for the produce. Forward or backward linkages in the supply chain do not exist. Farmers prefer to sell to the village merchants by taking the produce to nearby road head or depots.

2.6.4.9. Selection of extraction technologies

A wide range of technologies are available for extraction of active components and essential oils from medicinal and aromatic plants. Thus, proper selection of the extraction method, design and material of fabrication of the equipment and processing parameters play vital roles in determining the quality and yield of an essential oil and oleoresins (Silva *et al*., 2005; ICS-UNIDO, 2008). The choice depends on the economic feasibility, quality and suitability of the process to the particular situation (ICS-UNIDO, 2008).

The process of extracting medicinal and aromatic plants determines how efficiently we add value to bioresources. In the case of essential oils and oleoresins, the extraction process affects the physical as well as internal composition. External appearances, at times, can result in rejection of the batch even if the analytical results are within acceptable limits. Furthermore, essential oils and oleoresins are evaluated internationally for their olfactory properties by experienced perfumers and these olfactory qualities supersede analytical results. Variations in the chemical constituents of the extracts of medicinal and aromatic plants may result by using non-standardized procedures of extraction. Efforts should be made to produce batches with quality as consistent as possible (within the narrowest possible range) (Silva *et al*., 2005).

Distillation with Clevenger apparatus and hot continuous extraction (Soxhlet) methods are still the most economical methods of essential oil and oleoresin extraction, respectively which prove to be true economy because of high yield, good and highly stable oil and oleoresin quality and good market value (UNIDO and FAO, 2005). The advantage of these methods, compared to other methods (Essential oil extraction methods: Hydro-distillation,

Water and steam distillation, Steam distillation and Solvent extraction; Oleoresin extraction methods: maceration, infusion, percolation, digestion and decoction), large amounts of essential oil and oleoresin can be extracted with a much smaller quantity of solvent (UNIDO and FAO, 2005; ICS-UNIDO, 2008). This affects tremendous economy in terms of time, energy and consequently financial inputs. At small scale, it is employed as a batch process only, but it becomes much more economical and viable when converted into a continuous extraction procedure on medium or large scale (ICS-UNIDO, 2008).

3. MATERIALS AND METHODS

A study was conducted at Sheka zone in Southwestern Ethiopia starting from November 2010 to assess the influence of harvesting stages drying materials and drying durations on the quality of *A. corrorima*. The materials used and the methods followed during the execution of the study are elaborated in this chapter.

3.1. Description of the Study Area

The present study was conducted in Southwestern Ethiopia, SNNPR, Sheka Zone. The region includes the upper catchments of several important rivers, such as Baro, the Akobo and Omo. The rainfall distribution follows a bimodal pattern with an annual average rainfall of 2000mm, the wet seasons being between April/May and October/November. The temperature of the region ranges from 12^{o}C to 27.50^{o}C the average being around 19.75^{o}C. A large portion of the region is still covered with its natural vegetation consisting of tropical Montane humid forests. Currently, some of these forests are in different degrees of degradation (NTFP-PFM, 2006). The population consists of several ethnic groups who have lived there for centuries, as well as immigrants, mostly from Oromia and Amhara regions. Sheka Zone has a high population density of approximately 77 per KM^2. About 92% of the population is living in rural areas around the dense natural forests, while the rest (8%) lives in small urban centers (NTFP-PFM, 2006; Bureau of Agriculture and Rural Development of Sheka Zone, 2010).

Fresh *A. corrorima* capsules were collected from forests of Sheka Zone, Masha Woreda, Beto Kebele (Appendix Figure 1) which is located 680 KM far from Addis Ababa found in the Southern Nations, Nationalities, and Peoples Region (SNNPR) with 7°44′N latitude, 35°29′E longitude and altitude range of 1800 to 2222 meter above sea level (m.a.s.l.) (Appendix Figure 1) (Bureau of Agriculture and Rural Development of Masha Woreda, 2010).

The drying operation was performed at Tepi Coffee Plantation Development Enterprise which is located 611KM from Addis Ababa with 7^{o}30′N latitude, 35^{o}E longitude, 1200 m.a.s.l. altitude, Dystric Nitisol and it is dominated by a loam soil texture (Girma and Kindie, 2008), 80 to 90% relative humidity, annual rainfall of 1688mm and mean

minimum and maximum temperature of 15.30^{o}C and 29.5^{o}C, respectively (Edossa, 1998). Extraction of oleoresin and essential oil, determination of moisture content of dried capsule and seed color were conducted at Jimma University, Chemistry Department, Organic Chemistry Laboratory while determination of crude fiber, total ash and dry matter content of dried seeds were conducted at JUCAVM, Animal Science Department, Animal Nutrition Laboratory.

3.2. Experimental Material, Treatments and Design

Aframomum corrorima capsules were harvested from the natural forest of Sheka Zone, Masha Woreda in Southwestern part of Ethiopia. Forest plots for harvesting were selected from the Woreda that have moderate to good performance of *A. corrorima* and with minimum wild animal disturbance. Purposive sampling was used to collect the capsules. The forest plots were selected towards the middle of the forest as boundaries are most probably prone to disturbance. All types of capsules to be harvested were highly available towards the middle of the forests (50m from boundary of the forests). Thus the capsules of all harvesting stages were collected from the middle of the forest within a day. Hand picking was used for harvesting of the capsules by experienced collectors. The crop was found in the forth stratum of the forest association which is occupied by shade-obligate species.

The treatments consisted of 3*3*3 factorial combinations of three harvesting stages (Mature Green, MG, Mature Semi-red, MS and Mature Red, MR, (Appendix Figure 2)), three drying structures (Ground, G, Cement floor, C and raised beds with wire mesh, W) and three drying durations (Ten days, D_1, Fifteen days, D_2 and Twenty days, D_3) laid out using Completely Randomized Design (CRD) with 3 replications. Therefore, there were 27 treatments combinations as indicated in table 1.

3.3. Collection, Drying and Extraction Procedures

After the time of maturity had been reached, three maturity stages of mature capsules (MG, MS and MR) (Appendix Figure 2) were identified to harvest capsules from the forest of Masha Woreda, Beto Kebele, on 23 November 2010. Criteria for the maturity

Table 1. Treatment combination details

Drying structures	Harvesting stages	Drying durations (Days)	Treatment combination
	Mature Green (MG)	10 (D_1)	$CMGD_1$
		15 (D_2)	$CMGD_2$
		20 (D_3)	$CMGD_3$
Cement floor (C)	Mature Semi-red (MS)	10 (D_1)	C MSD_1
		15 (D_2)	C MSD_2
		20 (D_3)	C MSD_3
	Mature Red (MR)	10 (D_1)	$CMRD_1$
		15 (D_2)	$CMRD_2$
		20 (D_3)	$CMRD_3$
	Mature Green (MG)	10 (D_1)	$GMGD_1$
		15 (D_2)	$GMGD_2$
		20 (D_3)	$GMGD_3$
Ground (G)	Mature Semi-red (MS)	10 (D_1)	$GMSD_1$
		15 (D_2)	$GMSD_2$
		20 (D_3)	$GMSD_3$
	Mature Red (MR)	10 (D_1)	$GMRD_1$
		15 (D_2)	$GMRD_2$
		20 (D_3)	$GMRD_3$
	Mature Green (MG)	10 (D_1)	$WMGD_1$
		15 (D_2)	$WMGD_2$
		20 (D_3)	$WMGD_3$
Wire mesh (W)	Mature Semi-red (MS)	10 (D_1)	$WMSD_1$
		15 (D_2)	$WMSD_2$
		20 (D_3)	$WMSD_3$
	Mature Red (MR)	10 (D_1)	$WMRD_1$
		15 (D_2)	$WMRD_2$
		20 (D_3)	$WMRD_3$

stage of the capsules were based on visual observation of their physical appearance, color and size. Besides, easiness to detach the capsules from the mother plant and complete dry up at the tip of the capsule (straw like at the tip of the capsule) were also taken into account. Capsules which were free from insect damage, unbleached, uniform in color per each stage were considered during the harvesting time. About 85kg fresh capsules for each harvesting stage were collected on the same day. The capsules in each harvesting stages were then divided to 27 treatments having equal amount of fresh capsules (3kg/treatment). The three harvesting stages were randomly placed on the three types of drying structures. Capsules were then exposed to three different drying durations. The drying operation was performed during the sunny days starting from 9:00AM to 5:00PM, covered with water proof two fold plastic from above and sack beneath the plastic during midday, when there was rain and at night. The drying activity was performed from 25 November 2010 to 25 December 2010 being the extra 10 days were to compensate for the time lost during

inconvenient condition for drying. Immediately after the final drying activity of the samples, dried capsules were stored under ambient temperature until they undergo laboratory extraction of oleoresin and essential oil. Extraction was performed at Jimma University, Organic Chemistry and Animal Nutrition Laboratories. Data were recorded both on fresh capsule physical quality and dried capsule physical and chemical quality.

Vernier Caliper (FOWLER0531187, US) was used to measure the length and diameter of fresh and dried capsules/seeds. A three digit sensitive balance (AF 110L, China) was used for measuring any weight related parameters. Grinding machine (FZ 102 MICRO PLANT GRINDING MACHINE, UK) was used to crush the dried seeds for extraction purpose.

A hot continuous extraction (Soxhlet) method (Appendix Figure 3a) was used in the laboratory to extract oleoresin following the method described by ICS-UNIDO (2008). As outlined by Krishnamurthy *et al*. (1976) cited in Parthasarathy *et al*. (2008), oleoresin was recorded by the solvent extraction method using acetone (95%) as organic solvent for 4 to 5 hours. This method of extraction involved the complete setup of a mantle, 500ml round extraction flask, Soxhlet apparatus, condenser, porous bag (thimble), cotton, stand, reduced pressure rotary evaporator, gas pump, gas pump oil and vacuumed desiccators. A sample of 100g crushed (homogenized) fine powder (50 mesh size) of dried seeds was taken for extraction purpose. For extraction of oleoresin using Soxhlet apparatus, first the powder was added into the extractor. Then, 500ml of 95% aqueous acetone was used. Next, powdered sample was put into the porous bag (thimble) and placed into the Soxhlet apparatus and then boiled at a temperature of 56^{o}C for 4 hours.

Solvent removal from the sample plus all of the extractable (known as the miscella) was carried out using reduced pressure Rotary Vacuum Evaporator (LABOROTA 4000, Heidolph) (Appendix Figure 4b) at 40^{o}C and 90RPM speed to separate and get viscous oleoresin and solvent. Reduced pressure Rotary Vacuum Evaporator, gas pump, two round flasks and clump were used in the setup. Lastly the samples were added into 25ml beakers and placed into air vacuum desiccators having anhydrous sodium sulfate beneath for about 15 to 20 days to remove the residual solvent remaining with oleoresin (Appendix Figure 5).

Distillation with Clevenger apparatus (Appendix Figure 3b) was used for essential oil extraction. Seeds and husks of capsules of *A. corrorima* were separated and powdered just before the start of the distillation process. Crushed (homogenized) (25 mesh size) of dried seeds and husks were taken separately and weighed 100g coarse powder from each sample and placed into a 2000ml capacity round flask having 1000ml water. The flask was then placed on the mantle and pressurized steam was introduced into a lower chamber of the round flask and passed through the powder to vaporize the volatile oils in the plant material. The steam and oil vapor mixture was passed through a condenser. The essential oil was then extracted from the floral water or hydrolat in the separator. The separator consisted of aroma water below the essential oil, thus the essential oil and water were separated by separator funnel (ICS-UNIDO, 2008) (Appendix Figure 6). The distillation process was done at temperature of 80^{o}C for 5 hours after the mixture started boiling following the method described by Hymete *et al*. (2006), Garg *et al*. (1999) and Silva *et al.* (2005). The essential oils (Appendix Figure 7) were stored at 1°C to 2°C in test tubes.

Total ash content was determined by ignition procedure (Appendix Figure 8b). A muffle furnace (KARL KOLB N7 220 V1N, West Germany) was used for determination of total ash content of seeds. Crushed (homogenized) fine powder (50 mesh size) of dried seeds was taken and weighed 5g from each sample and placed in to a known weight of crucible. The crucible with its sample was then placed in muffle furnace; switch on the power and keeping it until the temperature reaches 550±10^{o}C. The temperature regulator adjusted to 550±10^{o}C and the ignition process was continued for 4 to 5 hours until all the organic matter was oxidized and lost as CO_2. The crucible containing sample was finally taken with the help of pair of tongs after the temperature dropped to 100^{o}C. The residual remained in crucible represents inorganic constituents of the air dried seeds (a total ash/minerals) while the lost in weight is taken as organic matter (OM).

Moisture content of dried seeds was determined using the procedure described by AOAC (1993) and Galyean (1997). Oven (KARL KOLB N7 220 V1N, West Germany) drying was used for determination of moisture content of seeds and capsules. Crushed (homogenized) fine powder (50 mesh size**)** of dried seeds was taken and weighed 5g from each sample and placed in to a crucible. The crucible with its sample was then placed in the oven at 105^{o}C for 24 hours (until all the moisture was lost). Thus, the residual

remained in crucible represents dry matter of the air dried seeds while the lost in weight is taken as moisture content of the sample.

Crude fiber was determined by Soxhlet digestion procedure (Appendix Figure 8a). Coarse Fiber Determinater (HUAYE - SLO-6, China, Shanghai) and muffle furnace were used for determination of crude fiber content of seeds. One gram of fine powder (50 mesh size) of dried seeds was weighed and put in to a Pyrex beaker. The Pyrex beakers were placed under the Soxhlet exactly fitted to each other. Boiled 30ml of 1.25% H_2SO_4 was added to the Pyrex beakers containing the sample, immediately switching on power, connecting to water pump and allowed boiling for exactly 30 minutes at 100^oC. The residue was thoroughly washed with boiled water before adding of NaOH. Boiled 30ml of 1.25% NaOH was then added to the Pyrex beakers containing the sample and immediately switch on power and connect to water pump and allowed boiling for exactly 30 minutes at 100^oC. The samples were then transferred to crucible. The crucible with sample was allowed to dry at 105±1^oC in air oven for 2 hours and then it was cooled and weighed. The process of oven drying and weighing was repeated for 30 minutes until constant weight was maintained. Finally, the sample was incinerated to muffle furnace at 550±10^oC until all the carbonaceous matter was burnt. The crucible containing the fiber then cooled down in a desiccator and weighed.

Determination of crude fiber was done following the procedure of Krishnamurthy *et al*. (1976) cited in Parthasarathy *et al*. (2008) and Van Soest and McQueen (1973) cited in Galyean (1997) where the crude fiber was determined by solvent extraction using H_2SO_4 and NaOH solutions each solvent for exactly 30 minutes. The determination procedure was based on acid and alkali hydrolysis. This method of extraction involved the complete setup of Coarse Fiber Determinater, Soxhlet apparatus with its condenser, Pyrex beakers, muffle furnace, oven and vacuumed desiccators.

3.4. Data Collected

Data were collected for both fresh and dried *A. corrorima* capsules. Data for dried capsules were taken after the three harvesting stages exposed to three drying durations on three drying structures. Individual parameters were recorded from ten randomly selected and tagged capsules from the sample except for total ash, crude fiber, oleoresin and dry

matter content of dried seeds; essential oil content of dried seeds and husks, moisture content of dried seeds, color of dried seeds and dried thousand seed weight.

3.4.1. Physical quality of fresh capsules

Weight of single fresh capsule (WSFC) (g): The average weight of singe capsule of ten sampled capsules was determined for all treatments of the experiment by using three digit sensitive balance (AF 110L, China).

Length and diameter of fresh capsules (cm): Average capsule length and diameter were taken by measuring the already tagged capsules of each treatment by using Vernier Caliper.

3.4.2. Physical quality of dried capsules

Weight of single dried capsule (WSDC) (g): Average weight of singe capsule was determined using three digit sensitive balance (AF 110L, China) by taking the already tagged capsules per treatment.

Dry weight recovery of dried capsules (DWR) (%): Average dry weight recovery was determined by taking weight of the already tagged capsules of each treatment. It was calculated as:

$$DWR(\%) = \left(\frac{WSDC}{WSFC}\right) X\ 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots Equation\ 1$$

Where: DWR = Dry weight recovery
WSDC = Average weight of single dried capsule
WSFC = Average weight of single fresh capsule

Moisture loss (ML) (%): Average moisture loss was determined by taking weight of the tagged capsules of each treatment and average moisture loss was calculated as:

$$ML(\%) = \left(\frac{WSFC - WSDC}{WSFC}\right) X\ 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots Equation\ 2$$

Where: ML = Moisture loss

WSDC = Average weight of single dried capsule

WSFC = Average weight of single fresh capsule

Weight of dried seeds per capsule (WSC) (g): Average weight of seeds per capsule was determined by taking the seeds of the tagged capsules of each treatment.

Length and diameter of dried capsule (cm): Average length and diameter of dried capsule were determined in cm using Vernier Caliper (FOWLER0531187, US) by measuring length and diameter of ten sampled capsules per each treatment.

Diameter of dried seed (DS) (mm): Average diameter of dried seed was calculated by taking ten seeds per each of the tagged capsules of each treatment by using Vernier Caliper (FOWLER0531187, US).

Thousand seed weight of dried seeds (TSW) (g): Immediately after the seeds detaching from the husk in the laboratory, average thousand seed weight was determined by taking thousand seed randomly per one treatment.

Dried seed to husk ratio (SHR): Average weight of husk per capsule was determined by taking the weight of the tagged capsules of each treatment and average seed to husk ratio was calculated as the proportion of average weight of seeds and average weight of husk per capsule.

$$SHR = \left(\frac{Average\ Weight\ of\ Seed\ per\ Capsule\ (g)}{Average\ Weight\ of\ Husk\ per\ Capsule\ (g)}\right) \ldots\ldots\ldots\ldots Equation\ 3$$

Dried seed to mucilage ratio (SMR): Average weight of mucilage per capsule was determined by taking weight of the tagged capsules of each treatment and average seed to mucilage ratio was calculated as the proportion of average weight of seeds and average weight of mucilage per capsule.

$$SMR = \left(\frac{Average\ Weight\ of\ Seed\ per\ Capsule\ (g)}{Average\ Weight\ of\ Mucilage\ per\ Capsule\ (g)}\right) \ldots\ldots\ldots\ldots Equation\ 4$$

Color of dried capsules and dried seeds: Data on color of died capsules and dried seeds of the capsules were recorded subjectively.

3.4.3. Chemical quality of dried capsules

Dry matter content of dried seeds (DM) (%): Dry matter of dried seeds was calculated as a percentage of the oven dried powder of dried seeds.

$$DM(\%) = \left(\frac{((W2 + C1) - W1)}{(W3 - W2)}\right) X\ 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots Equation\ 5$$

Where: DM = Dry matter

W1 = Weight of empty crucible (g)

W2 = Weight of oven dried ash + crucible (g)

W3 = Weight of initial sample + crucible (g)

C1 = correction factor for W2 read from the balance (due to hot weighing)

Total ash content of dried seeds (TAC) (%): was calculated as

$$TAC(\%) = \left(\frac{((W3 + C1) - W2)}{W1}\right) X\ 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots Equation\ 6$$

Where: TAC = Total ash content

W1 = Weight of Initial Sample (g)

W2 = Weight of empty crucible (g)

W3 = Weight of Ash + crucible (g)

C1 = correction factor for W3 read from the balance (due to hot weighing)

Crude fiber content of dried seeds (CF) (%): Crude fiber content was calculated as

$$CF(\%) = \left(\frac{((M2 + C1) - M)}{S}\right) X\ 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots Equation\ 7$$

Where: CF = Crude fiber

M1 = Weight of empty crucible in g

M2 = Weight of crucible in g containing ash

S = Weight of initial sample in g

C1 = correction factor for W2 read from the balance (due to hot weighing)

Moisture content of dried capsules (MCC) (%): Moisture content of dried capsules was calculated as a percentage of weight loss due to oven drying over night at 105°C.

$$MC(\%) = \left(\frac{(W2 - (W3 + C1))}{(W2 - W1)}\right) X\ 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots Equation\ 8$$

Where: MC = Moisture content

W1 = Weight of empty crucible (g)

W2 = Weight of dried capsules + crucible (g)

W3 = Weight of oven dried capsules + crucible (g)

C1 = correction factor for W3 read from the balance (due to hot weighing)

Moisture content of dried seeds (MCS) (%): Dried seeds were ground to fine powder and placed in oven over night at 105°C. Moisture content of dried seeds was then calculated as a percentage of weight loss due to oven drying.

$$MC(\%) = \left(\frac{(W2 - (W3 + C1))}{(W2 - W1)}\right) X\ 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots Equation\ 9$$

Where: MC = Moisture content

W1 = Weight of empty crucible (g)

W2 = Weight of dried seeds + crucible (g)

W3 = Weight of oven dried seeds + crucible (g)

C1 = correction factor for W3 read from the balance (due to hot weighing)

Oleoresin content of dried seeds (OLS) (%W/W): Oleoresin content of dried seeds of the spice was extracted by using Soxhlet extraction method. The oleoresin content per 100g powder was recorded in percent weight by weight.

Essential oil content of dried seeds (EOS) (%V/W): Essential oil content of dried seeds was extracted by using distillation with Clevenger apparatus and the amount of EO per 100g powder was measured in percent volume by weight.

Essential oil content of dried husk (EOH) (%V/W): Essential oil content of dried husks was extracted by using distillation with Clevenger apparatus and the amount of EO per 100g powder was measured in percent volume by weight.

3.5. Data Analysis

The data were subjected to analysis of variance (ANOVA) using SAS version 9.2 statistical computer software (SAS Institute Inc., 2008). The classical fixed effect analysis of variance model that includes the main effects of harvesting stages, drying structures and drying durations together with interaction effects were used. Mean comparison was undertaken with Least Significant Difference (LSD) at required levels of probability ($p = 0.05$) when significant treatment effects observed. Square root transformation was carried out for dried capsule and seed color for the sake of normality. A simple Pearson's correlation analysis was carried out to assess the relationships among response quality parameters.

4. RESULTS AND DISCUSSION

The analysis of variance of the results indicated that harvesting stages showed significant difference on weight of single fresh capsule, fresh capsule length and diameter of fresh capsule. The effect of drying durations and the interaction effect between harvesting stages and drying structures showed significant difference on color of dried capsules and seeds while the three way interaction effect among various harvesting stages, drying structures and drying durations showed significant difference on the physical and chemical quality of *A. corrorima* dried capsules and/or seeds (Appendix Tables 2 to 7). Hence, the results are presented and discussed hereunder.

4.1. Physical Quality of Fresh *A. corrorima* Capsules

4.1.1. Weight of single fresh capsule

The main effect of different harvesting stages showed a significant ($p<0.0001$) difference on average weight of single fresh capsule (Appendix Table 2). However, the main effect of drying structures and drying durations as well as the interaction effect among and/or between harvesting stages, drying structures and drying durations on average weight of single fresh capsule were found to be non-significant. The different harvesting stages viz. early, medium or late harvesting affected the average weight of single fresh capsule. As a result, the maximum average weight of single fresh capsule was obtained from mature green capsules (25.65g) whereas the minimum result was recorded from mature red capsule (22.52g) (Fig. 1). The maximum value of average weight of single fresh capsule was greater than the minimum and grand mean by 12.2% and 7.49%, respectively. This could be attributed to the presence of high moisture content in mature green capsules and commencement of metabolic activity for initiation of ripening which could decrease stored carbohydrates and moisture content of mature red capsules. Capsules may undergo increased respiration just after physiological maturity during ripening (Giovannoni, 2001) which could result in loss of water and stored products thereby imparting a negative effect on the weight of the capsules.

The values recoded here in this study are supported by the report of Zenebe (2004) in which the weight of single fresh capsule of *A. corrorima* varies from 25g to 27g. On the other hand, Thomas *et al*. (2009) and Varadarasan and Biswas (2002) reported on weight of single fresh capsule of cultivars of *Amomum subulatum 'varlangey' and Amomum subulatum 'golsey'* to be 8g and 4.5g, respectively. However, the maximum result of the study on *A. corrorima* fresh capsules was 68.81% and 82.46% greater than the finding of Thomas *et al*. (2009) and Varadarasan and Biswas (2002), respectively. Unfortunately, most reports never mention the stage of harvest when discussing mean weight of single fresh capsule.

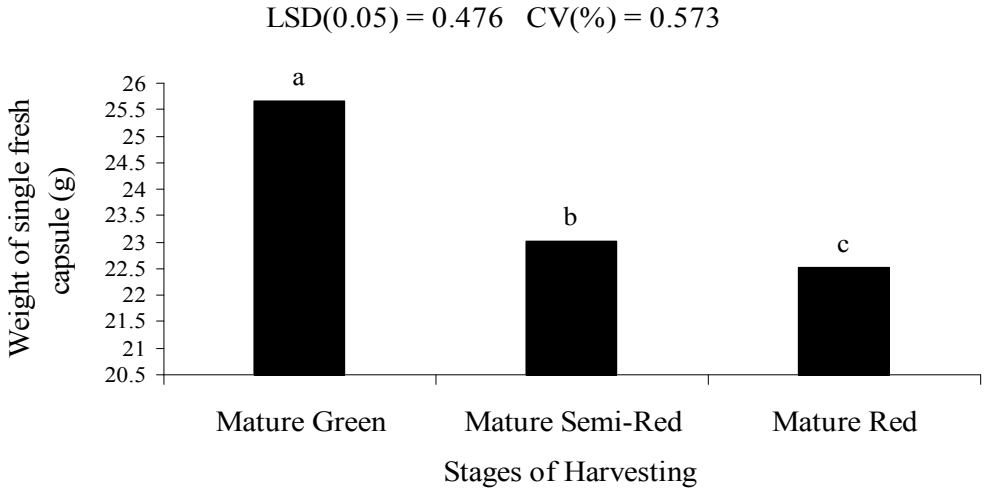


Figure 1. Effect of different harvesting stages on average weight of single fresh capsule of *A. corrorima*

4.1.2. Length and diameter of fresh capsule

Results pertaining to average fresh capsule length and diameter are illustrated in Fig. 2. and Fig. 3, respectively. The various harvesting stages significantly ($p<0.0001$) affected average fresh capsule length and diameter of *A. corrorima* (Appendix Table 2). Mature red capsules showed the maximum capsule length (6.18cm) whereas mature green capsules recorded the shortest average fresh capsule length (5.94cm). Mature semi-red capsules scored statistically similar result to mature green capsules. However, the main effect of drying structures and drying durations and the interaction effect among and/or between harvesting stages, drying structures and drying durations on average fresh capsule length were found to be non-significant. Similar to the phenomenon observed in respect of

capsule length, mature red capsules showed the highest average diameter of fresh capsule (3.71cm) which was statistically at par with mature semi-red capsules (3.66cm). On the contrary, the lowest average diameter of fresh capsule (3.51cm) was recorded from mature green capsules.

When the harvesting stage extended from mature green to mature red, average fresh capsule length and diameter were increased by 0.2cm. This may be attributed to continued cell enlargement during ripening which could increase the size of the husk thereby size of the capsules. According to Giovannoni (2001), the ripe phenotype is the summation of chemical and physiological changes that occur at the terminal stage of fruit development. The changes during ripening generally include modification of cell wall ultra structure and texture (increase cellulose), conversion of starch to sugars, alterations in pigment biosynthesis and accumulation of flavor and aromatic volatiles. Increase in cellulose content contributes to the capsule length and diameter change. Thus, delaying harvesting of capsules, from mature green to mature red stage, may lead to the advantage of increasing the length of capsules. However, size of seeds might remain relatively constant after physiological maturity as there could not be further grain filling while the color of seeds changed to dark brown.

Perhaps changes in chemical composition associated with ripening might have resulted in apparent variation in the length and diameter of capsules. The ripening of capsules arises from a complex of chemical and physiological changes (Giovannoni, 2001). The increase in diameter of fresh mature capsules with ripening may be due to the chemical changes resulted from ripening which could increase the cellulose content of the husk thereby the size of the capsule. As a result, the length and diameter of mature red did happen to be relatively better.

These results fit to the work of Jansen (1981), who reported the length and diameter of fresh capsule of *A. corrorima* as 6cm and 3.5cm, respectively. According to Thomas *et al*. (2009), length and diameter of fresh capsule of cultivar of *Amomum subulatum 'varlangey'* varies from 3cm to 4cm and 2cm to 2.75cm. Varadarasan and Biswas (2002) as well reported that the average fresh capsule length and diameter of *Amomum subulatum* cultivars; *Golsey* and *Ramsey* reaches up to 2.46cm and 2.27cm; 3.92cm and 2.5cm, respectively, which obviously is due to genetic differences among these species.

Moreover, Aubertin (2002) reported that capsule length in the case of large cardamom (*Amomum* spp.) is 2cm. However, the maximum result from the current study on *A. corrorima* revealed that the average length and diameter of fresh capsule were 2.18cm to 3.18cm and 1 cm to 1.71cm, respectively, greater than the report of Thomas *et al*. (2009).

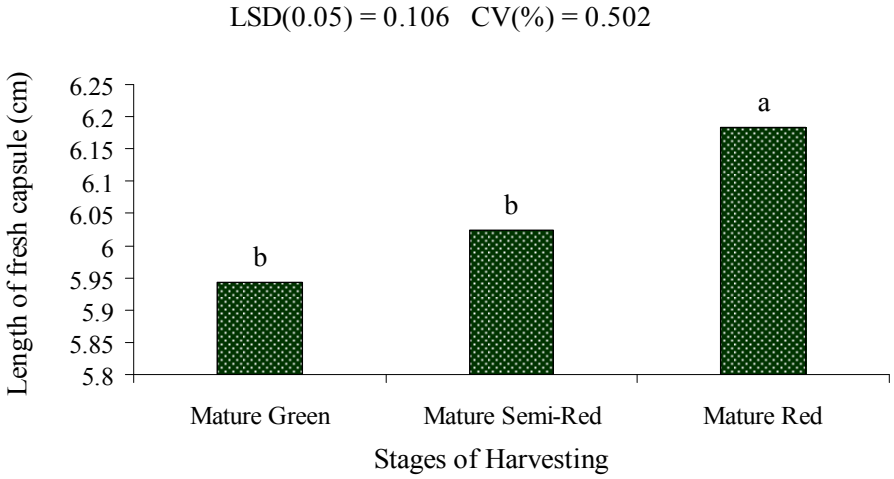


Figure 2. Effect of different harvesting stages on average length of fresh capsule of *A. corrorima*

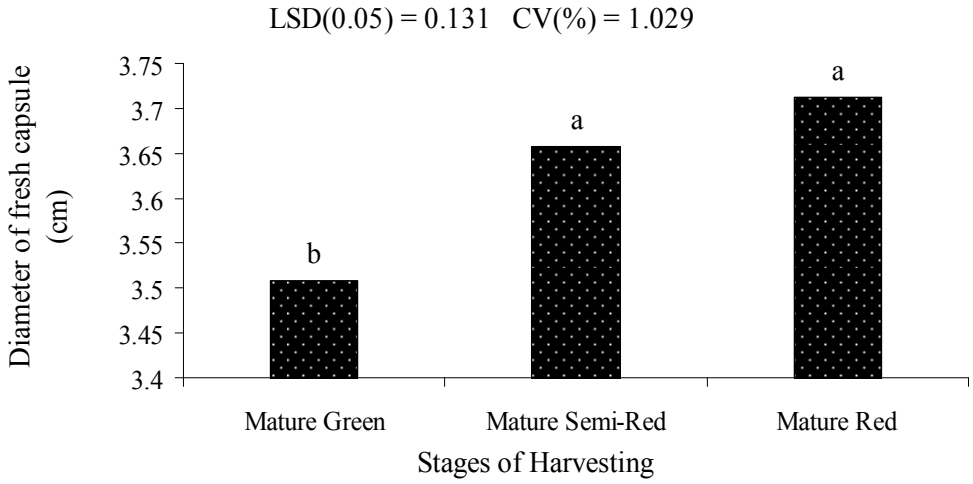


Figure 3. Effect of different harvesting stages on average diameter of fresh capsule of *A. corrorima*

Generally, the stage at which capsules of *A. corrorima* are picked showed a significant influence on the average weight, length and diameter of individual capsules. This observed difference among the harvesting stages was due to their ripening stage and perhaps decrease moisture content and increase thickness of husk of matured capsules up on ripening. It is unambiguous that significant main effect from the drying structures, drying duration and

interaction among and/or between the treatment levels could not be observed before they have been exposed to drying duration and drying structure except from the main effect of harvesting stages.

4.2. Physical Quality of Dried *A. corrorima* Capsules

4.2.1. Weight of single dried capsule

The average weight of single dried capsule was significantly ($p<0.0001$) (Appendix Table 3) influenced by the interaction of harvesting stages, drying structures and drying durations. The highest value for average weight of single dried capsule was obtained from mature green capsules (9.53g) which recorded statistically similar results with mature semi-red capsules (9.42g) both of which were dried on wire mesh for 10 days. On the contrary, the lowest weight of dried individual capsules was recorded from mature green stage capsules harvested and dried on cement floor for 20 days (5.89g) which was statistically at par with capsules of similar harvest maturity and drying structure drying duration of 5 days (6g) (Table 2). The lowest value was about 37.26% less than the highest value of average weight of single dried capsule and the maximum value recorded 17.73% higher than the grand mean. In general values were recorded from drying structure of wire mesh while all the least values were recorded from drying structure of cement floor. During harvesting, mature green capsules had a higher moisture content which subsequently leads to more moisture loss upon extended drying as compared to mature semi-red and mature red capsules. Comparatively speaking, in the initial drying duration (10 days), the mature green capsules dried on wire mesh might have conserved relatively more of their moisture content. Observation during the experiment revealed that drying on cement floor had raised temperature owing to its high solar heat absorbing nature resulted from the three forms of heat transfer (conduction, convection and radiation) taking place for a relatively longer time, thus, the capsules could easily loss their weight while wire mesh drying structure had hot air circulating nature during the day and cold air during the night, hence, the capsules dried slowly. However, with extended drying duration, loss of weight was observed higher in mature green capsules.

To date, there is no report available pertaining to weight of single dried capsule of *A. corrorima* from different harvesting stages dried on different drying structures for

different drying durations. However, Zenebe (2004) reported that the weight of single dried capsule of *A. corrorima* could vary from 4.31g to 5.61g. There is also a report by Feleke (2007) on weight of single dried capsule of *A. corrorima* purchased from central market of Addis Ababa (Mercato, Ethiopia, the largest open market in Africa) which were brought from different areas of the country (Ye-Basketo, Ye-Gofa, Ye-Bonga and Ye-Kafa). The maximum value registered in the current study was 29.56% higher than the maximum value reported by Feleke (2007) for capsules collected from Gofa (6.71g). The variation in length and diameter of these capsules could be attributed to genetic differences, environmental and soil factors.

On the other hand, Thomas *et al*. (2009) and Varadarasan and Biswas (2002) had reported on weight of single dried capsule of large cardamom cultivars, *Amomum subulatum 'varlangey' and Amomum subulatum 'golsey',* as 1.6g and 1g, respectively. Comparatively, the maximum weight recorded in the present study on *A. corrorima* dried capsule is 83.11% and 89.45% greater than the finding of Thomas *et al*. (2009) and Varadarasan and Biswas (2002), respectively.

4.2.2. Dry weight recovery of dried capsule

Results of the current investigation signified that the interaction effect among the various harvesting stages, drying structures and drying durations significantly ($p<0.0001$) affected the *A. corrorima* capsules average dry weight recovery of dried capsules (Appendix Table 3). As presented in Table 3, the maximum value was recorded from mature red capsules harvested and dried on wire mesh for 10 days (41.3%) which was, however, statistically the same with the values registered for mature semi-red capsules harvested and dried on wire mesh for 10 days whereas the minimum result was recorded from mature green capsules harvested and dried on cement floor for 20 days (23%). The later value was statistically at par with those of mature green capsules dried on cement floor for 15 days. Irrespective of the drying structure and drying duration, the maximum average percent dry weight recovery was recorded from mature red capsules (35%). The increase in dry weight recovery with ripening may be due to the accumulation of certain assimilates (crude fiber and cellulose). Upon ripening, cellulose and fiber content of capsules increase while moisture content and volatiles decrease. The seeds from ripened capsules have dark reddish brown color, possible minimum moisture and are hardened. During harvesting,

mature green capsules have high moisture content which is subsequently lost upon drying as compared to mature semi-red and mature red capsules. Likewise, as the drying duration is extended, average dry weight recovery decreased as there was high exposure to solar radiation and high loss of constituents from all capsules in general and the mature green capsules in particular. Combined with these, wire mesh drying structure had resulted in high dry weight recovery which might be due to low exposure to solar radiation, convection (cold and hot air circulation) and slow drying which might result less loss of moisture, volatiles and non-volatiles. Drying on cement floor coupled with mature green capsules dried for 15 and 20 days, on the other hand, resulted in low dry weight recovery which might be attributed to its solar heat absorbing nature that in turn result in high loss of moisture, volatiles and non-volatiles. Closer observation during the study showed that capsules harvested at mature stage manifested much less splitting of capsules during drying as compared to mature red capsules. Recent reports similarly indicate that splitting of capsules is less when picked at mature stage wherein incidence varied from 13.5% in physiologically mature capsules, to 41.5% in fully mature (ripe) capsules (Zachariah and Korikanthimath, 2002).

Peter (2001) and Zachariah and Korikanthimath (2002) reported that the percentage recovery of small cardamom capsules was 29% in ripened stage, 24% in physiologically mature stage and 14% in immature stage. Zachariah and Korikanthimath (2002) had further reported that there was 100% weight gain from immature to mature harvesting stage. Peter *et al*. (2007) as well reported similar result on dry weight recovery of small cardamom capsules which was greater than 22%. The current study showed 29.85%, 34.07% and 35% average dry weight recovery from mature green, mature semi-red and mature red dried *A. corrorima* capsules, respectively. Furthermore, the present study indicated, an overall average dry weight recovery of *A. corrorima* capsules to be about 19.62% higher than those of small cardamom capsules reported by Peter (2001) and Zachariah and Korikanthimath (2002). Hence, it might be ideal to pick *A. corrorima* capsules at the just ripened stage (mature red) or physiologically mature stage with drying period of 10 days on wire mesh as far as dry weight recovery is concerned.

Table 2. Interaction effect among different harvesting stages, drying structures and drying durations on weight of single dried capsule (g) of *A. corrorima*

Drying Structures	Harvesting Stages by Drying Durations								
	Mature Green			Mature Semi-red			Mature Red		
	10 Days	15 Days	20 Days	10 Days	15 Days	20 Days	10 Days	15 Days	20 Days
Cement	6.840^{l}	5.998^{o}	5.894^{o}	7.010^{kl}	6.621^{m}	6.427^{n}	7.098^{k}	6.941^{kl}	6.641^{m}
Ground	8.746^{de}	7.638^{i}	6.950^{kl}	8.334^{g}	8.028^{h}	7.450^{j}	7.949^{h}	7.769^{i}	7.760^{i}
Wire mesh	9.526^{a}	8.816^{cd}	8.485^{fg}	9.415^{ab}	8.752^{de}	8.537^{f}	9.287^{b}	8.927^{c}	8.637^{ef}
Grand Mean = 7.795			LSD (0.05) = 0.171			CV (%) = 1.341			

Means sharing the same letter(s) are not significantly different at p = 0.05 according to LSD test.

Table 3. Interaction effect among various harvesting stages, drying structures and drying durations on dry weight recovery of dried capsules (%) of *A. corrorima*

Drying Structures	Harvesting Stages by Drying Durations								
	Mature Green			Mature Semi-red			Mature Red		
	10 Days	15 Days	20 Days	10 Days	15 Days	20 Days	10 Days	15 Days	20 Days
Cement	26.584^{o}	23.389^{p}	22.999^{p}	30.443^{jk}	28.741^{m}	27.921^{n}	31.490^{i}	30.767^{ij}	29.478^{lm}
Ground	34.155^{g}	29.771^{kl}	27.055^{o}	36.145^{e}	34.910^{fg}	32.390^{h}	35.237^{f}	34.583^{fg}	34.227^{g}
Wire mesh	37.223^{d}	34.411^{g}	33.093^{h}	40.875^{a}	38.019^{c}	37.172^{d}	41.301^{a}	39.579^{b}	38.340^{c}
Grand Mean = 32.974			LSD (0.05) = 0.766			CV (%) = 1.420			

Means sharing the same letter(s) are not significantly different at p = 0.05 according to LSD test.

4.2.3. Moisture loss of capsules upon drying

Results presented in Table 4 revealed that the interaction effect among the various harvesting stages, drying structures and drying durations significantly ($p<0.0001$) affected average moisture loss of *A. corrorima* capsules (Appendix Table 3). The highest value was recorded from mature green capsules harvested and dried on cement floor for 20 days (77%) which was statistically at par with mature green capsules dried on cement floor for 15 days (76.61%). In contrast, the least values were recorded from mature red capsules harvested and dried on wire mesh for 10 days (58.7%) and mature semi-red capsules harvested and dried on wire mesh for 10 days which were statistically similar with each other. Mature green capsules harvested and dried on cement floor experienced high moisture loss due to more exposure to solar radiation and depletion of moisture in the sample. It is apparent that when harvesting stage is prolonged, moisture content decreased due to metabolic activity for ripening take place which may result reduction of moisture content. As a result, mature green capsules had high initial moisture and experienced high moisture loss upon drying, owing to extended drying and cement drying structure. Comparably speaking, mature green capsules harvested and dried on all drying structures were recorded high moisture loss with extended drying duration.

According to Zenebe (2004), fresh *A. corrorima* capsules may lose 60% to 65% moisture content upon drying. Based on the result reported by Zachariah and Korikanthimath (2002), cardamom capsules at harvest, depending on the degree of maturity, carry moisture levels of 70% to 80% which has to be brought down to 8% to10% by curing. Peter (2001) and George *et al*. (2007) as well stated that small cardamom capsules consist of 80% moisture which could be reduced 12% to 14% moisture content during curing. Karansinh (2002) further reported that fresh cardamom capsules generally contain 80% to 85% moisture which has to be dried immediately after harvesting to bring down its moisture content to less than 10% through drying. All these reports indirectly indicated the amount of moisture loss during drying. Thus, the current study is in line with all these findings in general and the report of Zenebe (2004) in particular.

4.2.4. Weight of dried seeds per capsule

A highly significant ($p<0.0001$) difference was observed on average weight of dried seeds per capsule due to the interaction effect among the various harvesting stages, drying structures and drying durations (Appendix Table 3). As a result, highest weight of dried seeds per capsule was recorded from mature green (6.42g), mature semi-red (6.38g) and mature red (6.32g) capsules harvested and dried on wire mesh for 10 days which were statistically similar with each other whereas the least values were obtained from mature green capsules harvested and dried either on cement floor for 20 days (3.89g) and 15 days (3.91g) (Table 5). The mature green capsules dried on wire mesh for 10 days attained 39.41% more weight than the mature green capsules dried on cement floor for 20 days.

The variation in terms of seed weight with harvesting stages might be attributed to accumulation of assimilates in the seed as well as high moisture content of seeds in the mature green capsules at harvest. Coupled with this, as the drying duration extended, weight of dried seeds per capsule was decreased as there was high exposure to solar radiation. However, the degree of loss was observed more stable in mature red capsules with extended drying duration. Wire mesh drying structure combined with early harvesting and short drying duration had resulted in high weight of dried seeds per capsule which could be accredited to limited exposure to solar radiation resulting from convectional movement of cold and hot air which might in turn have resulted slow drying and less and steady loss of moisture, volatiles and non-volatiles. Seeds with higher weight can be considered as those attaining higher percentage of assimilate, which is correlated with maturity of fruits and serve as reserve food during germination of seed and development of seedlings at early stage (Popova, 2009).

4.2.5. Length and diameter of dried capsule

The interaction effect among the various harvesting stages, drying structures and drying durations on average length and diameter of dried capsule were observed to be highly significantly ($p<0.001$) different (Appendix Table 4). The maximum capsule length (5.72cm) and diameter (2.77cm) were recorded from mature red capsules harvested and dried on wire mesh for 10 days while the minimum values capsule length (4.07cm) and

Table 4. Interaction effect among different harvesting stages, drying structures and drying durations on moisture loss capsule (%) of *A. corrorima*

Drying Structures	Harvesting Stages by Drying Durations								
	Mature Green			Mature Semi-red			Mature Red		
	10 Days	15 Days	20 Days	10 Days	15 Days	20 Days	10 Days	15 Days	20 Days
Cement	73.416^{b}	76.611^{a}	77.001^{a}	69.557^{fg}	71.258^{d}	72.078^{c}	68.510^{h}	69.232^{gh}	70.521^{de}
Ground	65.845^{j}	70.229^{ef}	72.945^{b}	63.854^{l}	65.090^{jk}	67.610^{i}	64.762^{k}	65.417^{jk}	65.773^{j}
Wire mesh	62.776^{m}	65.588^{j}	66.906^{i}	59.125^{p}	61.980^{n}	62.828^{m}	58.698^{p}	60.420^{o}	61.660^{n}
Grand Mean = 67.026				LSD (0.05) = 0.766			CV (%) = 0.699		

Means sharing the same letter(s) are not significantly different at p = 0.05 as established by LSD test.

Table 5. Interaction effect among different harvesting stages, drying structures and drying durations on weight of dried seeds per capsule (g) of *A. corrorima*

Drying Structures	Harvesting Stages by Drying Durations								
	Mature Green			Mature Semi-red			Mature Red		
	10 Days	15 Days	20 Days	10 Days	15 Days	20 Days	10 Days	15 Days	20 Days
Cement	4.385^{mn}	3.913^{o}	3.893^{o}	4.584^{kl}	4.450^{lm}	4.262^{n}	4.693^{jk}	4.609^{kl}	4.358^{mn}
Ground	6.022^{bcd}	5.164^{i}	4.841^{j}	5.669^{e}	5.545^{ef}	5.262^{hi}	5.435^{fg}	5.302^{ghi}	5.400^{fgh}
Wire mesh	6.415^{a}	6.075^{b}	6.007^{bcd}	6.379^{a}	6.049^{bc}	5.863^{d}	6.323^{a}	6.082^{b}	5.894^{cd}
Grand Mean = 5.292				LSD (0.05) = 0.169			CV (%) = 1.947		

Means sharing the same letter(s) are not significantly different at p = 0.05 as established by LSD test.

diameter (1.64cm) were recorded from mature green capsules harvested and dried on cement floor for 20 days period (Table 6 and Table 7, respectively).

It is vivid that the maximum values for length and diameter of dried capsule recorded 28.85% and 40.97% better than the minimum value of average length and diameter of dried *A. corrorima* capsules, respectively. The observed discrepancy might be accounted to the chemical changes resulted from ripening which could increase the size of the capsules and maintain the right size up on drying. According to Giovannoni (2001), the changes during ripening generally include modification of cell wall ultra structure and texture (increase cellulose), conversion of starch to sugars, alterations in pigment biosynthesis and accumulation of flavor and aromatic volatiles. Accumulation of carbohydrates (cellulose) contributes to the increase of cell size thereby size of the capsules. Besides, capsules harvested at mature green stage had high moisture content as compared to mature semi-red and mature red capsules. Thus, mature green capsules might have high tendency to lose higher moisture content and shrink at the expense of extended drying duration combined with cement drying structure. Wire mesh drying structure had resulted in longer length and diameter of dried capsule which might probably be due to low exposure to solar radiation that resulted from good cold and hot air circulation and the loss of moisture, volatiles and non-volatiles may be less relatively. On the contrary, cement floor drying structures had resulted in shorter length and diameter of dried capsule which could be attributed to its solar heat absorbing nature which in turn might have resulted in a higher loss of constituents of the capsule.

The presence of positive and significant correlation of diameter of dried capsule with weight of single dried capsule ($r = 0.32^{*}$), dry weight recovery ($r = 0.89^{***}$), oleoresin content of dried seeds ($r = 0.42^{***}$), essential oil content of dried seeds ($r = 0.52^{***}$) and essential oil content of dried husk ($r = 0.50^{***}$) (Appendix Table 8) may further indicate the size of dried capsules had positive contribution to the improvement of physical quality of *A. corrorima*.

The present result is in conformity with the report by Feleke (2007) on length of dried capsule of *A. corrorima* from different growing areas in southern southwestern parts of Ethiopia (Basketo, Gofa, Bonga and Kafa), with capsule length ranges of 4.6cm to 6.3cm. Jansen (1981) as well reported the length and diameter of dried *A. corrorima* capsule

collected from market varying from 3cm to 7cm and 1.5cm to 3.5cm, respectively. Furthermore, Hymete *et al*. (2006) reported that the length and diameter of dried capsule varied from 3cm to 6cm and 1.5cm to 3cm, respectively. On the other hand, reports by Kizhakkayil *et al*. (2006) showed relatively lower values of length of capsules of Indian (1.89cm), Sri Lankan (1.6cm) and Guatemalan cardamoms (1.95cm). Kizhakkayil *et al*. (2006) further reported on the diameter of Malabar cardamom capsules as 1.25cm.

4.2.6. Diameter of dried seed

The combined effect of the various harvesting stages, drying structures and drying durations resulted in a significant ($p<0.01$) difference in the average diameter of dried seed (Appendix Table 4). The results presented in Table 8 indicated that the highest dried diameter of seed was recorded from the combined interaction effects of mature red capsules dried on wire mesh for 10 days (5.27mm) followed by mature semi-red (5mm) and mature red (4.93mm) capsules dried on wire mesh for 10 and 15 days, respectively, while the minimum value was recorded from mature green capsules dried on cement floor for 20 days (2.27mm). About 56.93% difference was observed between the highest and the least results of average dried diameter of seed. Moreover, the maximum value recorded was 26.1% better than the grand mean. This indicates that the seeds obtained from mature red capsules dried on wire mesh for 10 days have less tendency to shrink and reduce in diameter may be due to high dry matter accumulation in seeds from fully ripened capsules, short period of exposure to solar radiation, convectional movement of cold and hot air and gradual drying characteristic of the drying structure.

The result of this study is in agreement with the report of Jansen (1981) who reported that the dried seed diameter of *A. corrorima* recorded from central market varied from 2mm to 5mm. On the other hand, Aubertin (2002) reported on average diameter of seed of cardamom (*Amomum* spp.) which varies from about 2mm to 3mm. According to these results, it can be said that the capsules of *Amomum* and *Aframomum* are much larger in size in comparison with capsules of *Elettaria cardamomum* and it is easy to distinguish them, but the seed size and anatomy are similar in all the three genera.

Table 6. Interaction effect among different harvesting stages, drying structures and drying durations on length of dried capsule (cm) of *A. corrorima*

Drying Structures	Harvesting Stages by Drying Durations								
	Mature Green			Mature Semi-red			Mature Red		
	10 Days	15 Days	20 Days	10 Days	15 Days	20 Days	10 Days	15 Days	20 Days
Cement	4.350^{kl}	4.193^{no}	4.065^{p}	4.593^{i}	4.293^{lm}	4.184^{o}	4.781^{g}	4.433^{jk}	4.245^{mno}
Ground	4.915^{f}	4.485^{j}	4.289^{lmn}	5.109^{e}	4.678^{hi}	4.365^{kl}	5.250^{cd}	4.893^{f}	4.602^{i}
Wire mesh	5.339^{c}	5.091^{e}	4.767^{gh}	5.500^{b}	5.185^{de}	4.964^{f}	5.721^{a}	5.450^{b}	5.292^{c}
Grand Mean = 4.779			LSD (0.05) = 0.097			CV (%) = 1.073			

Means sharing the same letter(s) are not significantly different at p = 0.05 as established by LSD test.

Table 7. Interaction effect among different harvesting stages, drying structures and drying durations on diameter of dried capsule (cm) of *A. corrorima*

Drying Structures	Harvesting Stages by Drying Durations								
	Mature Green			Mature Semi-red			Mature Red		
	10 Days	15 Days	20 Days	10 Days	15 Days	20 Days	10 Days	15 Days	20 Days
Cement	1.949^{lm}	1.768^{op}	1.637^{q}	2.054^{jk}	1.819^{no}	1.765^{p}	2.159^{gh}	1.982^{l}	1.911^{m}
Ground	2.087^{ij}	1.805^{nop}	1.763^{p}	2.295^{e}	1.980^{l}	1.855^{n}	2.411^{d}	2.138^{hi}	2.035^{k}
Wire mesh	2.471^{c}	2.093^{ij}	1.965^{l}	2.662^{b}	2.251^{ef}	2.202^{fg}	2.769^{a}	2.495^{c}	2.407^{d}
Grand Mean = 2.101			LSD (0.05) = 0.051			CV (%) = 1.289			

Means sharing the same letter(s) are not significantly different at p = 0.05 as established by LSD test.

4.2.7. Thousand dried seed weight

The result of the current study exhibited that the thousand seed weight of *A. corrorima* was affected significantly ($p<0.0001$) by the interaction effects of the harvesting stage, drying structure and drying duration treatments (Appendix Table 4). Accordingly, the combined effects of at mature green stage capsules harvested and dried on wire mesh for 10 days gave highest (30.82g) thousand seed weight of dried seeds which was followed by the treatment combination of mature semi-red capsules dried on wire mesh for 10 days (28.98g). On the other hand, the least value (18.24g) recorded was obtained from mature green capsules dried on cement floor for 20 days (Table 8). The maximum result registered was 40.82% and 22.71% greater than the minimum and the grand mean of thousand seeds weight, respectively. This may be due to the presence of high moisture content in mature green capsules at harvest joined with the nature of cement drying structure that increase loss of moisture from the seeds. Coupled with these, it is evident that as the drying duration is prolonged, the reduction in dried seed weight is increased, particularly in the mature green capsules due to greater loss of moisture as compared to capsules with advanced maturity. Moreover, simple Pearson's correlation among the response variables depicted positive and significant correlation of the thousand seeds weight with, moisture content of dried capsules ($r = 0.75^{***}$), total ash ($r = 0.89^{***}$) and oleoresin ($r = 0.70^{***}$) content of dried seeds and essential oil content of dried seeds ($r = 0.74^{***}$) and husk ($r = 0.74^{***}$) (Appendix Table 8).

According to the report of Holm and Slinkard (2002), thousand seed weight of selected progenies of small-fruited and large-fruited coriander cultivar varied from 8.1g to 10.4g and 9g to 12.4g, respectively, which are about half of the size of *A. corrorima* in this study. However, no report is available with regard to dried thousand seed weight of *A. corrorima* harvested from various stages, dried on various drying structures for various drying durations.

4.2.8. Dried seed to husk ratio

The interaction effect among the various harvesting stages, drying structures and drying durations showed a significant ($p<0.01$) difference in respect of seed to husk ratio

(Appendix Table 5). Accordingly, the highest average dried seed to husk ratio was recorded from at mature green stage capsules harvested and dried on wire mesh for 20 days ($WMGD_3$) (3.36:1). However, mature semi-red capsules harvested and dried on ground (3.36:1) for 20 days recorded statistically the same result with $WMGD_3$. In contrast, the lowest values were obtained from mature green capsules dried on cement floor either for 10 (2.42:1) or 15 (2.57:1) days mature semi-red capsules dried on cement floor for 10 days (2.59:1) which were statistically at par with each other (Table 8). In general, wire mesh and ground drying structures recorded higher average dried seed to husk ratios while capsules dried on cement floor resulted in lower seed to husk ratio. About 27.98% difference was observed between the highest and the lowest values of dried seed to husk ratio. Seed to husk ratio decreased in cement floor drying structure due to heat built up after exposure to solar radiation which in turn resulted in greater weight loss of seeds per capsule. Combined with this, as the drying duration and harvesting stage were extended, dried seed to husk ratio was increased owing to higher weight loss in husks than that of seeds. Lower seed to husk ratio is not recommended because the husk consumes much of the capsules' composition and the reverse is preferred in that high seed to husk ratio indicates the seed consumes and maintains much of the assimilates during maturation, harvest and drying steps. In short it implies that within the capsule the photosynthates were partitioned in such a way that seeds had more of the share. These could be further explained by positive and significant correlation of seed to husk ratio with dry weight recovery ($r = 0.41^{***}$), dried thousand seed weight ($r = 0.24^{*}$) and EO content of dried seeds ($r = 0.32^{*}$) (Appendix Table 8).

The result of the present study is in alignment with the reports of CFTRI (2008) who on the husk to seed ratio of large cardamom of Ramla variety (2.49:1). Similarly, Parthasarathy *et al*. (2008) reported 2.2:1 seed to husk ratio from *Amomum subulatum* grown in western regions of Sikkim, India. Furthermore, Kizhakkayil *et al*. (2006) reported variable values on seed to husk ratio of exported capsules of Indian (3:1), Sri Lankan (1.7:1) and Guatemalan (2.1:1) cardamoms. Apparently, seed to husk ratio of *A. corrorima* is comparably about 25.89% and 32.44% greater than those of large cardamom and small cardamom, respectively.

4.2.9. Dried seed to mucilage ratio

According to the results of this experiment, average dried seed to mucilage ratio showed a highly significant ($p \leq 0.001$) difference due to the interaction effect among the various harvesting stages, drying structures and drying durations (Appendix Table 5). Mature green capsules dried on ground for 10 days ($GMGD_1$) attained highest average dried seed to mucilage ratio (8.76:1) followed by mature green capsules harvested and dried on wire mesh and ground for 20 days as well as mature semi-red capsules dried on ground for 20 days with no difference among these values statistically. In contrast, the least values were recorded in mature red capsules dried on cement floor for 20 days (6.42:1), which was statistically at par with those of mature red capsules dried on cement floor for 15 days (Table 8).

Capsules dried on cement floor scored the least seed to mucilage ratio followed by wire mesh and ground drying structures, respectively. About 26.71% difference was observed between the highest and the least values. This probably indicate that average seed weight per capsule decrease more in cement floor drying structure as compared to the other drying structures as a result of strong exposure to solar radiation and loss of moisture compared to capsules dried on wire mesh and ground. Along with this, the different harvesting stages and drying durations contribute significantly to the variation of average dried seed to mucilage ratio due to differences in initial contents and depletion of moisture, volatiles and non-volatiles in the seeds and the mucilage. Lower seed to mucilage ratio is not recommended because the mucilage which is useless represents much of the capsules' composition. The greater the seed to mucilage ratio signifies the diversion to and contents of more photosynthates in the seed than the mucilage. This finding is consistent with the report of CFTRI (2008) in which the seed to mucilage ratio of large cardamom of Ramla variety was about 6.4:1.

4.2.10. Color of dried capsules

The results of the current experiment depicted that the interaction effect between harvesting stages and drying structures showed a significant ($p<0.05$) difference pertaining to color of dried capsules. However, the interactions between harvesting stages and drying durations, drying structures and drying durations and the three way interaction were found

Table 8. Interaction effect among different harvesting stages, drying structures and drying durations on diameter of dried seed, thousand dried seed weight, dried seed to husk ratio and dried seed to mucilage ratio of dried capsules of *A. corrorima*

Drying structures	Harvesting Stages	Drying durations	Diameter of seed (mm)	Thousand seed weight(g)	Seed to husk ratio	Seed to mucilage ratio
	Mature Green	10 Days	3.000^{n}	20.148^{q}	2.420^{l}	6.823^{hi}
		15 Days	2.433^{p}	19.382^{s}	2.567^{kl}	6.983^{gh}
		20 Days	2.266^{q}	18.240^{t}	2.676^{ijk}	7.112^{gh}
Cement	Mature Semi-red	10 Days	4.033^{i}	21.732^{o}	2.585^{jkl}	7.012^{gh}
		15 Days	3.533^{k}	20.248^{q}	2.849^{fghi}	7.307^{fg}
		20 Days	3.233^{m}	19.674^{r}	2.731^{ghijk}	7.116^{gh}
	Mature Red	10 Days	3.466^{k}	23.143^{lm}	2.686^{ijk}	7.136^{gh}
		15 Days	3.033^{n}	23.628^{k}	2.769^{ghi}	6.903^{gh}
		20 Days	2.766^{o}	21.186^{p}	2.715^{hijk}	6.424^{i}
	Mature green	10 Days	4.033^{i}	28.558^{c}	2.958^{def}	8.760^{a}
		15 Days	3.466^{k}	23.313^{l}	2.847^{fghi}	7.828^{cde}
		20 Days	3.333^{l}	20.086^{q}	3.160^{bc}	8.383^{ab}
Ground	Mature Semi-red	10 Days	4.733^{c}	26.054^{e}	2.891^{efg}	8.061^{bcde}
		15 Days	4.433^{f}	23.062^{m}	3.105^{bcd}	7.961^{cde}
		20 Days	4.166^{h}	22.034^{n}	3.360^{a}	8.458^{ab}
	Mature Red	10 Days	4.333^{g}	25.847^{h}	2.946^{def}	8.140^{bcd}
		15 Days	4.133^{h}	24.181^{j}	2.999^{cdef}	7.679^{ef}
		20 Days	4.000^{i}	23.162^{lm}	3.176^{b}	8.178^{bc}
	Mature green	10 Days	4.533^{e}	30.824^{a}	2.758^{ghij}	7.687^{ef}
		15 Days	4.033^{i}	27.247^{d}	3.048^{bcde}	8.118^{bcd}
		20 Days	3.633^{j}	23.093^{m}	3.361^{a}	8.696^{a}
Wire mesh	Mature Semi-red	10 Days	5.266^{a}	28.981^{b}	2.903^{efg}	8.121^{bcd}
		15 Days	4.933^{b}	26.195^{g}	3.080^{bcd}	8.199^{bc}
		20 Days	4.600^{de}	24.110^{j}	3.042^{bcde}	7.885^{cde}
	Mature Red	10 Days	5.000^{b}	27.252^{d}	2.890^{efgh}	8.136^{bcd}
		15 Days	4.666^{cd}	26.539^{f}	2.953^{def}	7.762^{de}
		20 Days	4.266^{g}	25.229^{i}	2.947^{def}	7.922^{cde}
Grand Mean			3.901	23.820	2.905	7.733
LSD (0.05)			0.186	0.214	0.176	0.410
CV (%)			0.477	1.533	3.693	3.243

Means within a column followed by the same letter(s) are not significantly different at p = 0.05 according to LSD tests.

to be non significant (Appendix Table 5). According to the illustration in Fig. 4, capsules harvested at mature red stage and dried on wire mesh recorded dark reddish brown capsule color. This might be due to the initial pigment development of the capsules at harvest coupled with nature of the drying structures that is, wire mesh drying structure maintaining good capsule color may be due to good convectional air movement result in gradual and slow drying. On the other hand, mature green capsules dried on cement and on ground gave brownish white color of capsules which were statistically similar to each

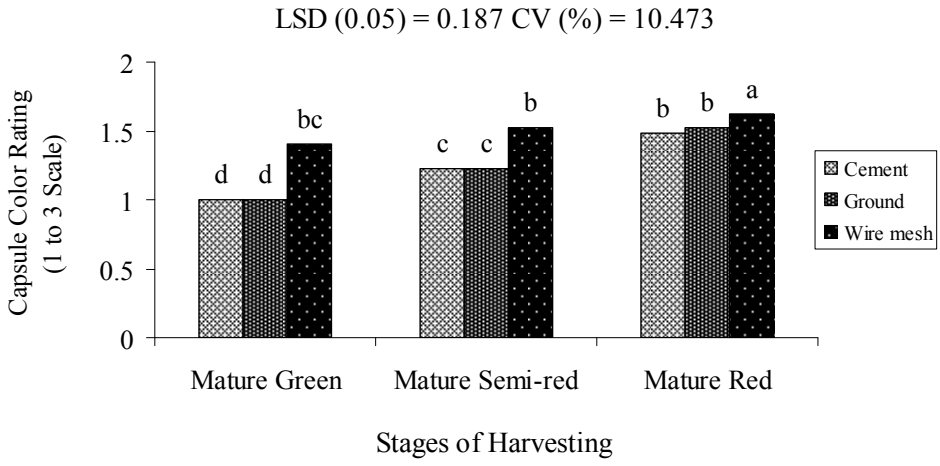
other and poor for color quality. Mature green capsules have high tendency of losing the green pigment owing to strong solar radiation resulted from heat absorbing nature of cement drying structure.

The main effect of the drying durations showed significant ($p \leq 0.0001$) variation on color of dried capsules. The result illustrated on Fig. 5 showed that brownish black dried capsule color was recorded from 10 days drying duration. In contrast brownish white dried capsule color was recorded from 20 days drying duration. It is apparent that as the drying duration extended the loss of color pigments will increase which could result in poor color of capsules (Girma *et al.* 2008).

The result is in agreement with the report of Jansen (2002), Eyob *et al*. *(*2008) and Girma *et al. (*2008) who indicated that the color of dried *A. corrorima* capsules is dark reddish brown, brownish black or grayish black with these differences probably arising from stage of maturity at harvest and/or drying durations in addition to genotypic variation in the crop.

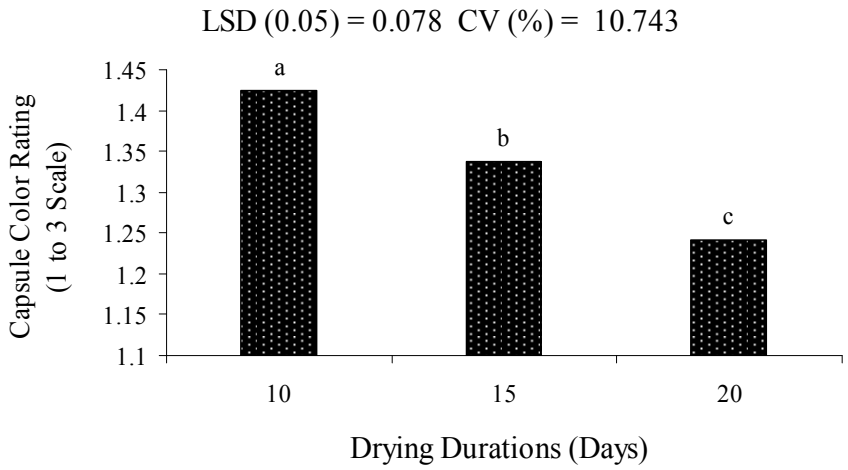
4.2.11. Color of dried seeds

There was a significant ($p<0.05$) difference in dried seed color of *A. corrorima* accountable to the interaction effect of the various harvesting stages and drying structures, however, the treatment combinations of between harvesting stages and drying durations, drying structures and drying durations and the three way interaction were found to be non significant (Appendix Table 5). According to the result illustrated in Fig. 6, mature red capsules dried on all drying structures and mature semi-red capsules harvested and dried On wire mesh recorded both brown seed color which were statistically similar to each other. On the other hand, mature green capsules dried on cement and on ground which was statistically similar to each other, gave brownish white dried seed color. This might be due to the rationale that just after physiological maturity, size of seeds might be remaining relatively constant while, color of seeds could be changed to dark brown up on ripening. The initial pigment of the seeds maintained during harvesting and nature of wire mesh drying structure with good convectional movement of cold and hot air and slow drying which helped to reduce pigment loss appear to result in good seed color.



Dark Reddish Brown =3, Brownish Black =2 and Brownish white =1; (*Square Root transformed*)

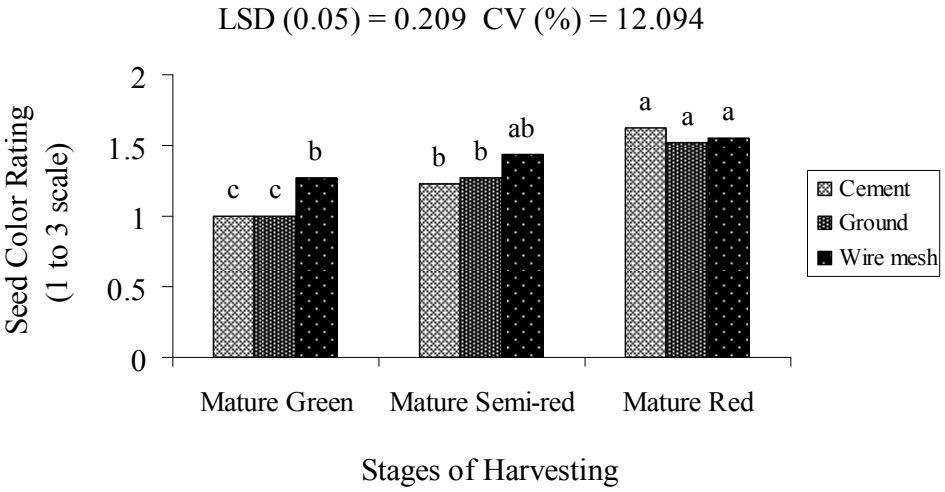
Figure 4. Interaction effect between different harvesting stages and drying structures on color of dried capsules of *A. corrorima*



Dark Reddish Brown =3, Brownish Black =2 and Brownish white =1; Square Root Transformed.

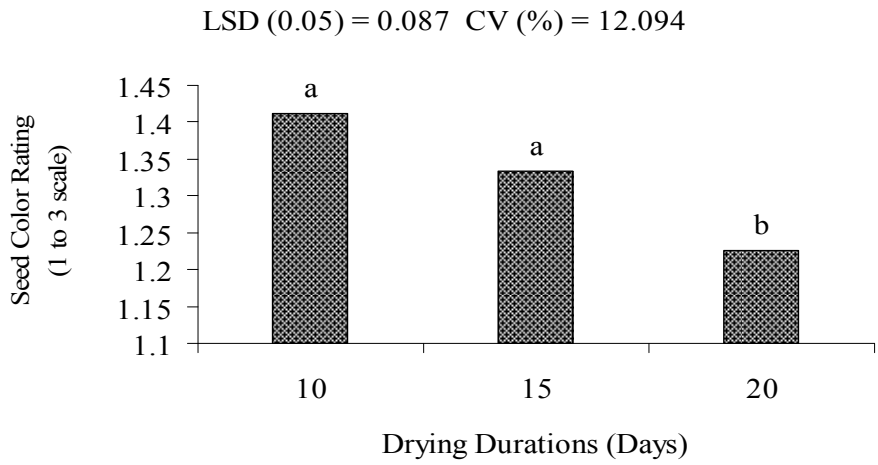
Figure 5. Effect of different drying durations on color of dried capsules of *A. corrorima*

Dried seed color was further highly significantly ($p \leq 0.0004$) affected by the main effect of drying durations. The result illustrated in Fig. 7 depicted that 10 days drying duration recorded brown seed color while, drying of the seeds for 15 days was observed to be statistically similar to the color of seeds dried for 10 days, brownish white seed color was noted after drying for 20 days. It is apparent that as the drying duration extended the loss of color pigments increased which could result in poor color of seeds. The result is in support of the present study, Jansen (2002), Eyob *et al. (*2008) and Girma *et al. (*2008). These authors reported that the color of dried *A. corrorima* seeds was dark brown.



Dark Brown =3, Brown =2 and Brownish white =1; Square Root Transformed.

Figure 6. Interaction effect between different harvesting stages and drying structures on color of dried seeds of *A. corrorima*



Dark Brown =3, Brown =2 and Brownish white =1; Square Root Transformed

Figure 7. Effect of different drying durations on color of dried seeds of *A. corrorima*

4.3. Chemical Quality of Dried *A. corrorima* Capsules

4.3.1. Dry matter content of dried seeds

The results of the experiment indicated significant ($p<0.0001$) interaction effects of the various harvesting stages, drying structures and drying durations on the dry matter content of seeds of *A. corrorima* (Appendix Table 6).

As presented in Table 9, the maximum dry matter of seeds was recorded from mature green capsules dried on cement floor for 20 days ($CMGD_3$) (93.12%). Likewise, both mature semi-red capsules harvested and dried on cement floor (92.61%) and mature green capsules harvested and dried on ground (92.45%) for 20 days recorded statistically similar results to $CMGD_3$. On the contrary, the minimum value was attained from mature green capsules harvested and dried on wire mesh for 10 days (83.51%) (Table 9). Mature green capsules dried on cement floor comprised higher dry matter content of seeds at the expense of high moisture loss from exposure to relatively more heat resulted from strong radiation on the cement drying structure and due to extended drying duration. As the harvesting stage prolonged from mature green to mature red, the proportion of dry matter content of seeds was found to be increased. This might be due to the fact that when ripening commenced following physiological maturity, metabolic activity will take place which may result in increase of dry matter content and reduction of moisture content of seeds. When the drying duration is extended from 10 to 15 and 20 days duration in combination to harvesting stages and drying structures, the proportion of dry matter of dried seeds similarly increased owing to high moisture loss. Dry matter content of dried seeds further explained by the presence of negative and very highly significant correlation with moisture content of dried capsules ($r = -0.96^{***}$) as clearly indicated in Appendix Table 8.

Though no information is published on the dry matter content of *A. corrorima*, the result of this study s in conformity with the findings of Bille and Shemkai (2006) in which the dry matter content of sun-dried and spiced-smoked *Dagaa* (*Rastrineobola argentea*) were 97.6% and 98.9%, respectively. However, the maximum dry matter content of dried seeds of the current study was found to be about 5% less than that of sun-dried and spiced-smoked *Dagaa,* which possibly could be due to intensity and duration of drying as well as moisture content at harvest.

4.3.2. Total ash content of dried seeds

The analysis of variance of the result from the present experiment indicated that the interaction effect among various harvesting stages, drying structures and drying durations on total ash content of dried seeds was significantly ($p \leq 0.01$) different (Appendix Table 6). The maximum value for the total ash content of dried seeds was recorded from mature

green capsules dried on wire mesh for 10 days (5.45%) which was statistically at par with wire mesh dried mature semi-red capsules (5.18%) and mature red capsules (5.12%) as well as mature green capsules dried on ground (5.09%) all for 10 days. On the other hand, the minimum value was registered from mature green capsules dried on cement floor for 20 days (3.43%) (Table 9). This is plausible that the maximum result is superior by almost 37.06% and 19.82% from the minimum result and grand mean, respectively. The combination of wire mesh drying structure, early harvesting and short period drying duration produced the highest total ash content of dried seeds. This might be basically due to late harvesting of the capsules. It is apparent that when ripening commenced following physiological maturity, metabolic activity will take place which may result in reduction of total ash content as minerals are used exhaustively.

The result is in conformity with the findings of Parthasarathy *et al*. (2008), Peter (2001) and Peter (2004) in which the total ash content of large cardamom was found to be 4.01%. Parthasarathy *et al.* (2008) as well reported the total ash content of dried seeds of large cardamom (*Amomum subulatum* Roxburgh) to be 4.01% and that of small cardamom (*Elettaria cardamomum* Maton) 5%. According to these findings, the maximum total ash content of dried seeds of *A. corrorima* is 26.42% higher than that of large cardamom and 8.26% than that of small cardamom. On the other hand, the grand mean total ash content of dried seeds of *A. corrorima* was 8.66% better than that of large cardamom and 12.2% less than that of small cardamom.

Moreover, total ash content of dried seeds was found to be positively and significantly correlated to oleoresin content of dried seeds ($r = 0.68^{***}$), essential oil content of dried seeds ($r = 0.64^{***}$) and manifested a negative and very highly significant correlation with crude fiber content of dried seeds ($r = -0.56^{***}$) (Appendix Table 8).

4.3.3. Crude fiber content of dried seeds

The result of this study showed significant interaction effects among the harvesting stages, drying structures and drying durations on crude fiber content of dried seeds of *A. corrorima* was found to be very highly significantly ($p<0.0001$) different (Appendix Table 6). Accordingly, the maximum crude fiber content of dried seeds was recorded from mature red capsules dried on cement floor for 20 days (22.85%), followed by ground dried

treatments involving mature red for 20 days (21.51%) whereas the minimum value was obtained from mature green capsules harvested and dried on wire mesh for 10 days (9.73%) (Table 9). This is clear that the maximum result exceeded the minimum value and grand mean by 57.42% and 25.34%, respectively. The combination of cement drying structure, late harvesting and extended period of drying duration produced the highest crude fiber content of dried seeds. Capsules harvested and dried on cement floor consisted of the highest proportion of crude fiber content of dried seeds due to high exposure to solar radiation and depletion of other chemical constituents which indirectly resulted in increased proportion of crude fiber available in the sample. It is apparent that when harvesting stage and drying duration are extended, crude fiber content of dried seeds is increased may be due to deterioration of volatiles and non-volatiles compounds and other chemical constituents owing to metabolic activity for ripening and the effect of light and heat from long drying period. Results were further explained by the presence of negative and very highly significant correlation with total ash content of dried seeds ($r = -0.56^{***}$), oleoresin content of dried seeds ($r = -0.82^{***}$), essential oil content of dried seeds ($r = -0.65^{***}$) and essential oil of dried husk ($r = -0.62^{***}$) as clearly indicated in Appendix Table 8.

The crude fiber content of dried seeds in this study was in accordance with the finding of Parthasarathy *et al*. (2008), Peter (2001) and Peter (2004) on the crude fiber content of large cardamom. Parthasarathy *et al*. (2008) also reported that the crude fiber content of small cardamom (*Elettaria cardamomum* Maton) was about 58.18% less than those of large cardamom (*Amomum subulatum* Roxburgh) and *A. corrorima* crude fiber content.

4.3.4. Moisture content of dried capsules

Moisture content of dried capsules was significantly ($p \leq 0.01$) affected by the interaction effect among the various harvesting stages, drying structures and drying durations (Appendix Table 6). The results presented in Table 10 depicted that the maximum value for moisture content of dried capsules was recorded from mature green capsules dried on wire mesh for 10 days (17.47%) followed by mature semi-red capsules dried on wire mesh for 10 days (16.89%). In contrary, the minimum value recorded was obtained from mature green capsules dried on cement floor for 20 days (7.96%) which was statistically similar to

Table 9. Interaction effect among various harvesting stages, drying structures and drying durations on dry matter content, total ash content and crude fiber content of dried seeds of *A. corrorima*

Drying structures	Harvesting Stages	Drying durations	Dry matter content of seeds (%)	Total ash content of seeds (%)	Crude fiber content of seeds (%)
	Mature Green	10 Days	88.626^{ijk}	4.154^{hijk}	16.015^{j}
		15 Days	91.705^{cd}	3.726^{n}	18.163^{f}
		20 Days	93.123^{a}	3.434^{o}	18.031^{f}
Cement	Mature Semi-red	10 Days	88.284^{kl}	4.299^{efghi}	18.385^{f}
		15 Days	90.952^{ef}	3.864^{mn}	19.356^{e}
		20 Days	92.607^{ab}	4.082^{jkl}	21.323^{b}
	Mature Red	10 Days	87.805^{l}	4.270^{ghij}	20.215^{cde}
		15 Days	90.370^{fg}	4.138^{hijk}	20.987^{bc}
		20 Days	92.436^{ab}	3.909^{lmn}	22.846^{a}
	Mature Green	10 Days	85.283^{o}	5.093^{b}	16.409^{ij}
		15 Days	89.239^{hi}	4.488^{def}	17.003^{hi}
		20 Days	92.454^{ab}	3.886^{lmn}	17.507^{fgh}
Ground	Mature Semi-red	10 Days	86.154^{n}	4.814^{c}	16.687^{hij}
		15 Days	90.110^{g}	4.342^{defgh}	17.903^{fg}
		20 Days	91.599^{cde}	4.126^{ijk}	20.284^{cd}
	Mature Red	10 Days	86.976^{m}	4.526^{d}	18.268^{f}
		15 Days	89.081^{ij}	4.390^{defg}	19.718^{de}
		20 Days	91.514^{cde}	4.254^{ghijk}	21.510^{b}
	Mature Green	10 Days	83.509^{p}	5.451^{a}	9.733^{n}
		15 Days	88.541^{ijk}	4.299^{efghi}	11.554^{m}
		20 Days	91.963^{bc}	4.050^{klm}	13.321^{kl}
Wire mesh	Mature Semi-red	10 Days	84.695^{o}	5.182^{b}	11.459^{m}
		15 Days	88.535^{ijk}	4.503^{de}	12.715^{l}
		20 Days	91.075^{def}	4.288^{fghij}	13.820^{k}
	Mature Red	10 Days	85.343^{o}	5.124^{b}	13.367^{kl}
		15 Days	88.482^{jkl}	4.772^{c}	17.077^{ghi}
		20 Days	89.876^{gh}	4.432^{defg}	16.955^{hi}
Grand Mean			89.272	4.367	17.060
LSD (0.05)			0.712	0.215	0.878
CV (%)			0.487	3.011	3.146

Means within a column followed by the same letter(s) are not significantly different at p = 0.05 as established by LSD test.

mature semi-red capsules dried on the same drying structure and drying duration 20 days (8.21%). Capsules harvested and dried on cement floor maintained low moisture content associated with more heat from exposure to solar radiation and depletion of moisture which resulted in increased proportion of dry matter available in the sample. It is clear that when harvesting stage and drying duration are extended, moisture content of dried capsules is decreased due to the commencement of metabolic activity for ripening which

increase concentration of solutes and result in the reduction of the proportion moisture in the capsules. In the same way, as the drying duration extended, moisture content of dried capsules decreased which can be due to depletion of moisture content of capsules owing to long time exposure.

According to Peter (2001) and George *et al*. (2007), a key issue in storage is maintaining the right level of moisture of capsules and/or seeds. They reported that the moisture content of capsules has to be brought down 12% to 14% to achieve a longer shelf-life. George *et al*. (2007) further reported that it is desirable to keep the moisture content of large cardamom capsules and seeds at 12%. Girma *et al*. (2008) and Zenebe (2004) as well reported that dried *A. corrorima* capsules have 12% moisture content. Based on the result reported by Zachariah and Korikanthimath (2002), moisture content of commercial small cardamom collected from market ranges from 7% to 20% depending on the regions and mode of curing. However, they found that 10% moisture is ideal which also depends on the type and nature of drying structure. Likewise, Raghavan (2007) reported that the moisture content of spices is generally 8% to 10%. The higher and lower values of the current study are not conducive because entirely dried capsules may lean to lose its natural taste to some extent whereas excessive moisture increase mould development up on storage which may reduce its value. Mature green (12.37%), mature semi-red (12.20%) and mature red (12.96%) capsules harvested and dried on wire mesh for 15 days and mature semi-red (11.24%) and mature red (12.04%) capsules harvested and dried on ground for 15 days recorded similar result to the finding of Girma *et al.* (2008), George *et al*. (2007) and Zenebe (2004).

4.3.5. Moisture content of dried seeds

Significant ($p<0.0001$) differences were observed in the moisture content of seeds as a result of the interaction effects among the harvesting stages, drying structures and drying durations (Appendix Table 7). The maximum value for moisture content of seeds was recorded from mature green capsules harvested and dried on wire mesh for 10 days (16.04%) followed by the statistically similar results recorded from mature semi-red (15.61%) and mature red (15.22%) capsules harvested and dried on wire mesh for 10 days. On the other hand, the minimum results were attained from mature green capsules harvested and dried on cement floor for 20 days (7.07%) and mature semi-red capsules

harvested and dried on cement floor for 20 days (7.37%) which were statistically similar to each other (Table 11). The low moisture content obtained from mature green capsules dried on cement floor for 20 days might be accredited to solar heat absorbing nature of the drying structure and extended exposure to heat which could result to depletion of moisture and increase in the proportion of dry matter available in the sample. Likewise, delayed harvesting stage could increase accumulation of assimilate reserve in the seed while decreasing the proportion of water in the seed. Correspondingly, as the drying duration extended, the degree of moisture loss was observed to be higher in mature green capsules, indicating initial high moisture content of seed in the mature green capsules.

Peter (2001), Peter (2004) and Parthasarathy *et al*. (2008) reported that the moisture content of large cardamom and small cardamom were 8.49% and 8.3%, respectively, which are relatively lower than the average than the observed in this study. On the other hand, George *et al*. (2007) reported that it desirable to keep the moisture content of large cardamom capsules and seeds at 12%, which is comparable to the moisture content of mature red (11.98%) and mature green (11.51%) capsules dried on wire mesh for 15 days in this study.

4.3.6. Oleoresin content of dried seeds

The results of the present study indicated that the interaction effects among various harvesting stages, drying structures and drying durations on oleoresin content of dried seeds were observed to be highly significantly ($p<0.001$) different (Appendix Table 7). The result presented in Table 12 explains that the maximum oleoresin content was recorded from mature green capsules harvested and dried on wire mesh for 10 days (10.04%) followed by mature green capsules dried on ground for 10 days (9.16%). In contrast, the minimum oleoresin was recorded from mature red capsules harvested and dried on cement floor for 20 days (4.87%). This is apparent that the maximum result exceeded 51.49% and 33.76% from the minimum result and grand mean, respectively. The oleoresin content of dried seeds is an important component consisting of all composition of the spice which may affect value of the commodity.

Table 10. Interaction effect among different harvesting stages, drying structures and drying durations on moisture content of dried capsules (%) of *A. corrorima*

Drying Structures	Harvesting Stages by Drying Durations								
	Mature Green (MG)			Mature Semi-red (MS)			Mature Red (MR)		
	10 Days	15 Days	20 Days	10 Days	15 Days	20 Days	10 Days	15 Days	20 Days
Cement	14.781^{e}	9.994^{kl}	7.964^{q}	13.419^{f}	10.485^{j}	8.209^{q}	13.425^{f}	11.031^{i}	8.702^{p}
Ground	16.640^{b}	10.970^{i}	8.811^{op}	15.859^{cd}	11.242^{i}	9.064^{no}	15.512^{d}	12.044^{h}	9.433^{m}
Wire mesh	17.472^{a}	12.365^{h}	9.404^{mn}	16.894^{b}	12.198^{h}	9.831^{l}	16.106^{c}	12.961^{g}	10.241^{jk}
Grand Mean = 12.039			LSD (0.05) = 0.349			CV (%) = 1.772			

Means sharing the same letter(s) are not significantly different at p = 0.05 according to LSD test.

Table 11. Interaction effect among different harvesting stages, drying structures and drying durations on moisture content of dried seeds (%) of *A. corrorima*

Drying Structures	Harvesting Stages by Drying Durations								
	Mature Green (MG)			Mature Semi-red (MS)			Mature Red (MR)		
	10 Days	15 Days	20 Days	10 Days	15 Days	20 Days	10 Days	15 Days	20 Days
Cement	11.403^{g}	8.642^{n}	7.067^{q}	12.056^{f}	9.586^{l}	7.374^{pq}	12.227^{f}	10.074^{jk}	7.701^{p}
Ground	14.501^{c}	10.592^{hi}	7.619^{p}	13.939^{d}	9.877^{kl}	8.136^{o}	13.027^{e}	10.796^{h}	8.591^{n}
Wire mesh	16.043^{a}	11.509^{g}	8.609^{n}	15.606^{b}	11.399^{g}	9.128^{m}	15.220^{b}	11.977^{f}	10.321^{ij}
Grand Mean = 10.853			LSD (0.05) = 0.424			CV (%) = 2.338			

Means sharing the same letter(s) are not significantly different at p = 0.05 according to LSD test.

Early harvested mature capsules and dried on wire mesh for short drying duration obtained high oleoresin content of dried seeds which could be due to convection (cold and hot air circulation) in the wire mesh drying structure. On the other hand, the oleoresin value of late harvested capsules dried on cement floor for longer time could partly be attributed to have got low oleoresin content at the expense of high exposure to solar radiation and depletion of the volatiles and non-volatiles which resulted in decreased oleoresin content in the sample. It is unambiguous that when harvesting stage is extended, oleoresin content decreases owing to the commencement of metabolic activity for ripening and expenditure of volatiles, non-volatiles and other chemicals.

The results can be further explained by the presence of a positive and very highly significant correlation of the oleoresin content with total ash content of dried seed ($r = 0.69^{***}$), essential oil content of dried seed ($r = 0.72^{***}$) and essential oil content of dried husk ($r = 0.7^{***}$). Nevertheless, it is negatively and very highly significantly correlated with crude fiber content of dried seed ($r = -0.36^{*}$) (Appendix Table 8).

No information is available on the oleoresin content of *A. corrorima*; however, some reports are available in related crops such as small and large cardamoms indicate the oleoresin value in this study to be comparable. For example, Endashaw (2007) reported that the oleoresin content of small cardamom varied from 7.9% to 8.2%. However, Peter (2001) further reported that the average yield of oleoresin content of large cardamom seeds was 4%. According to BeeHive Digital Concepts Cochin (2006), the mean oleoresin content from solar tunnel dried large cardamom ranged from 4.63% to 5.8%. Purseglove *et al*. (1981) as well reported that the oleoresin content of small cardamom is greater than 10%. The maximum oleoresin content of the current study was found to be about 60% greater than that of large cardamom indicated by Peter (2001) and Peter (2004). However, the average oleoresin content (6.65%) of the current study was 39.85% greater than the findings of Peter (2001) on large cardamom. On the other hand, the average oleoresin content of the current study was found to be about 33.5% less than that of small cardamom reported by Purseglove *et al*. (1981).

4.3.7. Essential oil content of dried seeds

The results of the current experiment revealed that the interaction effect among the various harvesting stages, drying structures and drying durations on essential oil (EO) content of dried seeds was observed to be very highly significant ($p<0.0001$) (Appendix Table 7). According to the result presented in Table 13, the maximum value for EO content of dried seeds was recorded from mature green capsules harvested and dried on wire mesh for 10 days (5.53%) which was statistically at par with mature semi-red capsules harvested and dried on wire mesh for 10 days (5.35%). On the other hand, the minimum EO was recorded from mature green capsules harvested and dried on cement floor for 20 days ($CMGD_3$) (2.82%). Mature semi-red capsules harvested and dried on cement floor for 15 days and 20 days both recorded similar value (3.05%) which was statistically similar to the result of $CMGD_3$. About 49.11% difference was recorded between the maximum and minimum results of EO content of dried seeds. Furthermore, the maximum result was found to be 24.95% higher than the grand mean. Early harvested mature capsules and dried on wire mesh for short drying duration obtained high EO content of dried seeds which could be due to high convectional movement of air in the wire mesh drying structure while cement floor drying structure scored low results due to higher solar radiation exposure. As harvesting stage was extended, the EO content of dried seeds was decreased. It is apparent that as ripening commences following physiological maturity, metabolic activity related to ripening process will be high use EO as substrate of respiration and thus reduce the EO content of dried seeds. Leela *et al*. (2008) proved this fact which stated that in all small cardamom genotypes, the highest mean EO yield was obtained at immature stage and physiologically mature stages whereas the least oil yield was recorded at fully ripe stage. Furthermore, essential oil content of cardamom was found to be 20 to 30 percent more in the physiologically mature and immature stages compared to ripe stage and half ripe stage (Zachariah and Korikanthimat, 2002). In the same way, when the drying duration extended the EO content of dried seeds was diminished which may be due to the volatility nature and heat sensitivity of the oils.

Eyob *et al*. (2007) stated that steam-distilled dried fruits gave about 3.5% pale yellow EO with a flat cineolic odor. Lawrence (1970) cited in Ravindran *et al*. (2002) as well as Endashaw (2007) had reported the same result of EO of *A. corrorima* which was 3.5% volume by weight. Hymete *et al.* (2006) further reported that dried seeds of *A. corrorima*

contain 3.77% EO. On the other hand, Parthasarathy *et al*. (2008) reported that EO of small cardamom (Indian) and large cardamom (Nepal) was 5.5% to 10% and 2.8%, respectively. Likewise, Peter (2001) had reported that EO of small cardamom (Indian; cultivars, Mysore and Malabar) and large (Nepal) cardamom was 6.6% to 10.6% and 2.8%, respectively. Furthermore, Raghavan (2007) had reported that the EO of small and large cardamom was 2% to 10% and 2%, respectively. In comparison of these reports with the current study, the average EO content of *A. corrorima* was about 48.25% less than and 42.03% greater than the average EO content of small cardamom and large cardamom, respectively. However, the result of the current study more likely agreed with the finding of Purseglove *et al*. (1981) who reported as the maximum EO content of *A. corrorima* is 4.5%.

4.3.8. Essential oil content of dried husk

The result of the current investigation exhibited significant ($p<0.0001$) differences in the essential oil (EO) content of *A. corrorima* that the interaction effects among the various harvesting stage, drying structure and drying duration treatments (Appendix Table 7). The maximum EO was recorded from mature green capsules dried on wire mesh for 10 days (0.93%) while the minimum values recorded were attained from mature green capsules harvested and dried on cement floor for 20 days (0.42%), mature semi-red dried on cement floor for 15 and 20 days, which were statistically similar to each other (Table 14). Cement floor drying structure combined with late harvesting stage and extended drying duration had resulted low EO content of dried husk which might be due to exposure to high solar radiation and as well as expenditure of these chemicals during ripening in capsules harvested in red ripe stage as explained in the previous section.

The present result is in agreement with that of Eyob (2007) who reported that the EO yield of pod of *A. corrorima* was 0.83% volume by weight on dried basis. Hymete *et al*. (2006) further reported that the EO content of dried husks of *A. corrorima* purchased from Merkato, and separated, powdered and undergone distillation had contained 0.27%. Parthasarathy *et al*. (2008) also reported the essential oil for large cardamom husk yielded 0.18% essential oil. The average result of the current study exceeded the finding of Hymete *et al*. (2006) by about 55% which might be due to differences in genotype, harvesting stages and drying conditions.

Table 12. Interaction effect among different harvesting stages, drying structures and drying durations on oleoresin content of dried *A. corrorima* seeds (%W/W)

Drying Structures	Harvesting Stages by Drying Durations								
	Mature Green (MG)			Mature Semi-red (MS)			Mature Red (MR)		
	10 Days	15 Days	20 Days	10 Days	15 Days	20 Days	10 Days	15 Days	20 Days
Cement	7.341^{g}	6.073^{m}	5.455^{o}	6.635^{j}	5.528^{o}	5.158^{p}	6.048^{m}	5.177^{p}	4.874^{r}
Ground	9.159^{b}	7.430^{g}	6.416^{k}	7.742^{e}	6.253^{l}	5.812^{n}	6.859^{i}	5.526^{o}	5.027^{q}
Wire mesh	10.035^{a}	8.443^{c}	7.549^{f}	8.284^{d}	7.074^{h}	6.491^{k}	7.069^{h}	6.214^{l}	5.777^{n}
Grand Mean = 6.646			LSD (0.05) = 0.112			CV (%) = 1.035			

Means sharing the same letter(s) are not significantly different at p = 0.05 according to LSD test.

Table 13. Interaction effect among different harvesting stages, drying structures and drying durations on essential oil content of dried *A. corrorima* seeds (%V/W)

Drying Structures	Harvesting Stages by Drying Durations								
	Mature Green (MG)			Mature Semi-red (MS)			Mature Red (MR)		
	10 Days	15 Days	20 Days	10 Days	15 Days	20 Days	10 Days	15 Days	20 Days
Cement	3.833^{ijk}	3.133^{l}	2.816^{m}	4.050^{fghi}	3.050^{lm}	3.050^{lm}	4.283^{ef}	3.200^{l}	3.200^{l}
Ground	5.116^{b}	4.533^{d}	4.033^{ghi}	4.866^{c}	4.283^{ef}	3.766^{jk}	4.450^{de}	4.200^{fg}	3.683^{k}
Wire mesh	5.533^{a}	5.116^{b}	4.533^{d}	5.350^{ab}	4.583^{d}	4.116^{fgh}	4.866^{c}	4.283^{ef}	3.950^{hij}
Grand Mean = 4.144			LSD (0.05) = 0.242			CV (%) = 3.567			

Means sharing the same letter(s) are not significantly different at p = 0.05 according to LSD test.

Table 14. Interaction effect among different harvesting stages, drying structures and drying durations on essential oil content dried *A. corrorima* husks (%V/W)

Drying Structures	Harvesting Stages by Drying Durations								
	Mature Green (MG)			Mature Semi-red (MS)			Mature Red (MR)		
	10 Days	15 Days	20 Days	10 Days	15 Days	20 Days	10 Days	15 Days	20 Days
Cement	0.526^{ijklm}	0.516^{jklm}	0.423^{n}	0.576^{ghij}	0.463^{mn}	0.476^{lmn}	0.640^{fg}	0.520^{ijklm}	0.493^{klm}
Ground	0.773^{bc}	0.713^{cde}	0.533^{ijkl}	0.720^{cd}	0.553^{ijk}	0.523^{ijklm}	0.650^{ef}	0.583^{ghi}	0.533^{ijkl}
Wire mesh	0.933^{a}	0.770^{bc}	0.630^{fg}	0.833^{b}	0.673^{def}	0.626^{fgh}	0.766^{c}	0.626^{fgh}	0.563^{hij}
Grand Mean = 0.616				LSD (0.05) = 0.067			CV (%) = 6.593		

Means sharing the same letter(s) are not significantly different at p = 0.05 according to LSD test.

5. SUMMARY AND CONCLUSION

Korarima (*Aframomum corrorima* (Braun) P.C.M. Jansen) is a warm season, shade obligate, high value spice, of which production is generally confined to areas where natural forests are often available. Ethiopia is a homeland of *A. corrorima* and other different indigenous species. *Aframomum corrorima* is one of the few under-exploited plant species with promising economic value for the country. It has been part of each and daily Ethiopian dish in preparation of curry powder for culinary purpose. The seeds have medicinal value in Ethiopia as carminative, tonic agent, purgative as well as laxative; however, there is a serious problem of quality on the local and international markets due to the absence of recommended post harvest practices pertaining to processing, value addition, packaging, storing, transporting and marketing. Most often capsules are harvested at mature/immature green stages. The drying structures and drying durations are also variable and have equal consideration with the harvesting stages on quality. Due to the presence of inappropriate stage of harvesting, drying structure and drying duration, it was assumed that there is a huge loss of income from the spice. Hence, it was found crucial to do a research on harvesting stages, drying structures and drying durations of *A. corrorima*. With these backgrounds, the objective of the present study was to determine the appropriate harvesting stages at maturity, drying structures and durations of drying for quality improvement of *A. corrorima* capsules. In order to pursue the research work, three harvesting stages (mature green, mature semi-red and mature red) capsules were harvested. For drying of these capsules, three drying structures namely cement floor, ground and raised wire mesh bed were prepared in combination with three different drying durations namely 10 days, 15 days and 20 days duration during the year 2010/2011 under open sun drying. The experiment was conducted using CRD design with 3*3*3 factorial arrangement with three replications.

In this study, the influence of the treatments on physical quality of fresh capsules as well as physical and chemical quality of dried *A. corrorima* capsules and seeds was investigated. The combined effect among the various harvesting stages, drying structures and drying durations showed significant effects on the physical and chemical quality parameters studied except in the case of dried capsule and seed color. The interaction

effect between harvesting stages and drying structures as well as the main effect of drying durations were significantly affected dried capsule and seed color.

Harvesting mature green capsules gave maximum weight of single fresh capsule while mature red capsules recorded maximum length and diameter of fresh capsule. In contrast, mature green capsules gave minimum average length and diameter while mature red capsules recorded minimum weight of single fresh capsule.

Mature green capsules harvested and dried on wire mesh for 10 days scored maximum weight of single dried capsule and dried thousand seed weight. Similarly, these capsules dried on ground for 10 days scored maximum average seed to mucilage ratio. On the other hand, mature semi-red capsules harvested and dried on wire mesh for 10 days and on ground for 20 days scored maximum average weight of seeds per capsule and average seed to husk ratio, respectively. Likewise, mature red capsules harvested and dried on wire mesh for 10 days scored maximum dry weight recovery, length and diameter of dried capsule.

On the contrary, the combined effect of mature green capsules dried on cement floor for 20 days scored minimum average weight of single dried capsule, dried thousand seeds weight and average weight of dried seeds per capsule. Similarly, mature green capsules dried on cement floor for 10 days, mature red capsules dried on cement floor for 20 days also gave minimum average seed to husk ratio and average seed to mucilage ratio, respectively.

In the case of chemical quality, mature green capsules harvested and dried on wire mesh for 10 days scored maximum total ash content of dried seeds (5.45%), moisture content of dried capsules and seeds, oleoresin content of dried seeds (10.04%), essential oil content of dried seeds and husk (5.53% and 0.93%, respectively). About 51.49% and 49.11%, differences were recorded between the maximum and minimum results of oleoresin and essential oil of dried seeds, respectively. It is interesting to note that, the maximum result of these quality parameters induced 33.76% and 24.95% from their grand mean, respectively. Furthermore, mature green capsules dried on cement floor for 20 days produced highest dry matter content (93.12%) and crude fiber content of dried seeds (22.85%).

On the other hand, the combined effect of mature green capsules dried on cement floor for 20 days as well scored minimum moisture content, essential oil content of dried seeds and husk. Furthermore, mature green capsules dried on wire mesh for 10 days gave minimum dry matter content of seeds and crude fiber content of seeds. Likewise, mature green capsules dried on ground for 20 days and mature red capsules dried on cement floor for 20 days also gave minimum total ash content of seeds (3.43%) and oleoresin content of seeds (4.87%), respectively.

As drying duration extended from 10 days to 15 days and then to 20 days, harvesting prolonged from mature green to mature red ripe and drying structures concerned moving from wire mesh to ground and then to cement, dry matter and crude fiber content of dried seeds found to be increased while total ash content of dried seeds, moisture content of dried capsules, oleoresin content of dried seeds and essential oil content of dried seeds and husks showed decreasing trend. This may be due to the fact that long time exposure to solar radiation combined with prolonged harvesting stage and nature of the drying structure. As the harvesting stage is prolonged, expenditure of chemical constituents (water, volatiles and non-volatiles) take place during ripening. Alongside, drying duration might result in depletion of the chemical constituents because of long period exposure to solar radiation. Coupled with these, cement drying structure with high solar heat absorbing nature, contributes to over drying of the capsules, resulting to high loss of volatiles and non-volatiles. The appropriate moisture content for dried capsules and seeds was recorded from all harvesting stages dried on wire mesh for 15 days duration. However, mature red ripe capsules had the optimum moisture content as far as shelf-life is concerned. Moreover, as the drying duration extended, the loss of chemical constituents was observed more stable in mature red capsules followed by mature semi-red capsules.

Therefore, it can be concluded that the result of the current study showed that the various harvesting stages and the interaction of various drying structures, harvesting stages and drying durations have sound impact on physical and chemical quality of *A. corrorima.* Generally, wire mesh drying structure was found to be consistently superior in resulting majority of the quality parameters and can be recommended for production of good quality dried *A. corrorima* capsules. Considering overall quality of the spice, the recommendations may be based on the purpose of the capsules intended for final use. If the capsules are intended for

immediate extraction purpose, mature green capsules harvested and dried on wire mesh for 10 days can be recommended for high oleoresin, total ash and essential oil production. However, for consumption and storage purpose of dry capsules, harvesting at mature red stage and drying on wire mesh for 15 days may be recommendable as far as external appearance and moisture level of the dried capsules is considered. Though external appearance (color) might not have contribution on the chemical production of the spice, at times, it can result in rejection of the batch even if the analytical results within acceptable limits. Color of the dried capsules is the first thing that directly comes to vision and attracts consumers. So, synchronizing might be needed to have acceptable good quality capsules in the local and international markets. Thus, collectors and/or producers in all *A. corrorima* growing areas better to be aware of the quality issues and may use the recommendations of this research work for maintenance of good quality of capsule, depending on the intended use.

Provided that equal opportunity in research and development, *A. corrorima* can be another gift of Ethiopia to the world and undoubtedly it can be the best candidate to rival with other commercial commodities, example coffee, both in the domestic and export markets. Thus, it appears to be worthy of considering further investigations in the aspects of storage shelf life of capsules, quality comparison of *A. corrorima* capsules dried by smoke, sunshine and shade, packaging and packaging materials as well as quality comparison of *A. corrorima* collected from different growing agro ecologies and with the other *aframomum*, *Amomum* and *Elettaria* species. Besides, characterization and adaptation trial of the different *A. corrorima* accessions to different agro ecologies of the country which might have a great contribution towards production increment should be taken in to consideration. Furthermore, there has not been any significant work done so far on the crop in Ethiopia with regard to conservation, sustainable research and extension. Along with the shade loving nature of the crop, well oriented development policy of agricultural investment towards agro ecological sustainability and giving adequate concern for the ever increasing habitat degradation of the natural forest that threatened the available diversity and its other properties also request a top urgent action from the research and biodiversity institutes. It is impressive that the chromosome number of the spice is still remained unknown. So further studies should be done to wards cytogenetics and genetic diversity of the crop.

6. REFERENCES

Anne, P., 2004. Turmeric: Post-Production Management Organization. EDs. Mazaud, F. Röttger, A. and Steffel, K. Food and Agriculture Organization of the United Nations (FAO), AGST.

AOAC, 1993. Forage Analysis Procedures. National Forage Testing Association, Omaha. Pp.111-117.

Aubertin, C., 2002. Cardamom (*Amomum* spp.) in Leo Leo People's Democratic Republic (PDR): the hazardous future of an agro forestry product.

Barry, J., 2005. Non-Timber Forest Products and Sustainable Forest Management, Taiga Rescue Network Factsheet. Taiga Rescue Network, Box 116, S-962 23 Jokkmokk, Sweden, *Journal of Sustainable Agriculture, Vol. 27 (1), 2005.*

Baser, K.H.C. and M. Kürkçüoglu, 2001. The essential oils of *Aframomum corrorima* (Braun) Jansen and *Aframomum angustifolium* K.Schum. *From Africa Journal of Essential Oil Research, 13: 208 - 209.*

BeeHive Digital Concepts Cochin, 2006. Strategies to Improve the Quality of Cardamom Cultivated in Kerala. Mahatama Gandhi University Kottayam, Kerala. (http://shodhganga.inflibnet.ac.in) (Accessed on 21 January 2011).

Bille, P. G. and R. H. Shemkai, 2006. Process Development, Nutrition and Sensory Characteristics of Spiced-Smoked and Sun-Dried *Dagaa* (*Rastrineobola argentea*) from Lake Victoria, Tanzania. *African Journal of Food Agriculture Nutrition and Development, Vol. 6, No 2.*

Birhanu, M., 2010. Determination of Some Major and Trace Metals Levels in Korarima (*A. corrorima*) Cultivated in the Southern and Southwestern Ethiopia. An M.Sc. Thesis presented to the School of Graduate Studies of Addis Ababa University, Ethiopia. 72p.

Bureau of Agriculture and Rural Development of Sheka Zone, 2010. Geographic and Demographic Description Sheka Zone, SNNPR. Unpublished document.

Bureau of Agriculture and Rural Development of Masha Woreda, 2010. Geographic Description of Masha Woreda, Sheka zone, SNNPR. Unpublished document.

CFTRI, 2008. Physicochemical analysis of large cardamom (Amomum Subulatum Roxb). University of Mysore Karala, India.

Chanyalew, Z. 1999. The Role of Spices in the National Economy of Ethiopia. Paper presented on the curriculum development workshop for diploma and degree program in horticulture at Jimma College of Agriculture. 6 to 7, August 1999, Jimma, Ethiopia.

Delin, W. and K. Larsen, 2009. Korarima (Ethiopian Cardamom) in Flora of China Vol. 24 . Science Press (Beijing) and Missouri Botanical Garden Press. Pp. 322.

EARO, 2000. National research strategy for spices, medicinal and other essential oil bearing plants. EARO, Addis Ababa, Ethiopia.

Edossa, E. 1998. Spices research achievements and experiences, Research report No. 33. Institute of Agricultural Research, Addis Ababa Ethiopia.

Endashaw, B., 2007. Study on Actual Situation of Medicinal Plants in Ethiopia. Prepared for Japan Association for International Collaboration of Agriculture and Forestry. Ethiopia. Pp. 48-65.

ESA, 2004. European Spice Association Quality Minima Document. Reuterstraβe151, D-53113 Bonn, Germany.

Ethiopian Investment Agency, 2010. Investment Opportunity Profile for Spice Processing in Ethiopia. Pp. 1-9.

Eyob, S., Tsegaye, A. and M. Appelgren, 2008. Analysis of Korarima (*Aframomum corrorima* (Braun) P.C.M. Jansen) indigenous production practices and farm based biodiversity in Southern Ethiopia. *Journal of Genetic Resources and Crop Evolution. Springer Netherlands, 56: 573-585.*

Eyob, S., M. Appelgren, J. Rohloff, Tsegaye A. and Messele G., 2007. Chemical composition of essential oils from fresh plant parts of korarima (*Aframomum corrorima*) cultivated in the highland of Southern Ethiopia. *Journal of essential oil research, 55: 205 - 220.*

Eyob, S., 2009. Potential of Korarima (*A. corrorima*) as a crop plant in Southern Ethiopia", is dealing with such a promising plant species. Ph.D. Dissertation, Hawassa, Ethiopia.(http://www.umb.no/ipm-en/article/new-crop-plants-2) (Accessed on 18 February 2011).

Eyob, S., M. Appelgren, J. Rohloff, Tsegaye A. and Messele G., 2008. Traditional medicinal uses and essential oil composition of leaves and rhizomes of Korarima (*A. corrorima* (Braun) P.C.M. Jansen*)* from Southern Ethiopia. *South Africa Journal of Botany, 74, 181-185.*

FBC, 2008. Product Chain Study Cardamom. Ministry of Agriculture and Cooperatives, Department of Agriculture, Biratnagar, Nepal. A report submitted by Full Bright Consultancy Pvt. Ltd. Pp. 1-27.

Fekadu, F., 2009. Spices Plants in Ethiopia; A Brief History of Spices in Ethiopia. Ee-JRIF, Ethiopia, Vol.1, No.1.

Feleke, W., 2007. The rich and the poor sources, quality and typicality of the grains of paradise from Ethiopia. Bernard Roussel (MNHN/IRD UMR "local Heritage", Paris). University of Arba Minch, Ethiopia.

Galyean, M. L.,1997. Laboratory Procedures in Animal Nutrition Research. Department of Animal and Food Sciences, Texas, Tech University, Lubbock. Revised edition, No. 13, PP 37-41.

Garg, S. N., R. P. Bansal, M. M. Gupta and S. Kumar, 1999. Variation in the rhizome essential oil and cucurmin contents and oil quality in the land races of turmeric Curcuma longa of North Indian plains. Central Institute of Medicinal and Aromatic Plants, CIMAP, Lucknow 226 015, India. John Wiley and Sons, Ltd., *Flavor and fragrance journal, 14: 315-318.*

George, C. K., R. Munankami and B. Bijl, 2007. Nepal Advisory Services on Export Development of Priority Sectors Sector Study on Large Cardamom. Project NEP/A1/01A, a project financed by the EU and ITC under the Asia Trust Fund, Nepal.

Giovannoni, J., 2001. Molecular Biology of Fruit Maturation and Ripening. USDA-ARS Plant, Soil and Nutrition Laboratory and Boyce Thompson Institute for Plant Research, Cornell University, Ithaca, New York. Plant Physiology. Plant Mol. Biol. 2001. 52:725-49.

Girma, H.**,** Digafie T., Ali M., Derbew B. and Amsalu N., 2009a. Effect of stage of maturity at harvest on the quality of different ginger cultivars in Southwestern Ethiopia, In: Lemma Dessalegne, Hailemichael K/Mariam, Asfaw Zeleke, Zemedu Worku, Eshetu Derso, Terefe Belehu and Getachew Tabor, (eds.) Proceedings of the Second Biennial Conference of EHSS, Volume II. 22-23 January, 2009, Addis Ababa, Ethiopia. Pp. 96-99.

Girma, H., Digafie T. and Tekaligne T., 2009b. Physical parameters, oleoresin and volatile oils content of five pepper (*Piper nigrum* L.) cultivars as influenced by maturity. Haramaya University, Ethiopia. *East African Journal of Sciences, Vol. 3(2), Pp. 189-192.*

Girma, H. and Kindie T., 2008. The effects of seed rhizome size on the growth, yield and economic return of ginger (*Zingiber officinale* Rose.). Asian Network for Scientific Information, *Asian Journal of Plant Sciences 7(2): 213-217.*

Girma, H., Digafe T., Edossa E., Belay Y., and Weyessa G., 2008. Spices research achievements, Revised Edition. Ethiopia Institute of Agricultural Research, Addis Ababa, Ethiopia.

Holm, F. A. and A. E. Slinkard, 2002. Spice Breeding and Agronomic Research. Crop Development Centre, Saskatchewan Herb and Spice Association, University of Saskatchewan.

Hymete, A., J. Rohloff and T. H. Iversen, 2006. Essential oil from seeds and husks of *Aframomum corrorima* from Ethiopia. *Flavor and fragrance Journal, 2006; 21: 642-644.*

IBC, 2005. National Biodiversity Strategy and Action Plan, Government of the Federal Democratic Republic of Ethiopia. Addis Ababa, Ethiopia.

ICS-UNIDO, 2008. Extraction Technologies for Medicinal and Aromatic Plants. ICS-UNIDO, AREA Science Park, Padriciano 99, 34012 Trieste, Italy.

IOSTA, 2008. General Guidelines for Good Agricultural Practices of Spices, Geneva, Switzerland. Pp. 4-20.

ITC, 2010. All ACP Agricultural Commodities Program. Spice Sub-Sector, A Strategy for Ethiopia, Submitted to the Government of Ethiopia.

Jansen, P.C.M. 1981. Spices, condiments and medicinal plants in Ethiopia, their taxonomy and agricultural significance. Joint venture of the college of Agriculture AAU, Ethiopia and the Agricultural University Wageningen, the Netherlands. Laboratory of plant taxonomy and plant geography, agricultural university Wageningen, the Netherlands. Agricultural Research Reports 906, Center for Agricultural Publishing and Documentation, Wageningen, Netherlands, 327: 10-20.

Jansen, P.C.M. 2002. "*A .corrorima* (Braun) P.C.M. Jansen) ". Record from Protabase. Oyen, L.P.A. and Lemmens, R.H.M.J. Editors. PROTA Plant Resources of Tropical Africa, Wageningen, the Netherlands.

Jose, K. P. and C. M. Joy, 2004. Postharvest Processing of Spices in Relation to Export Quality. Everyman's Science, Vol. XXXIX, No. 4., Kerala, India.

Joy, P. P., J. Thomas, S. Mathew, G. Jose and J. Joseph, 2005. Aromatic plants. Aromatic and Medicinal Plants Research Station, Odakkali Asamannoor - 683 549, Kerala, India.

Karansinh, V. Z., 2002. Quality improvement of large cardamom by using an advanced gasifier based dryer, Sikkim, India.

Kizhakkayil, J., E. Thomas, T. J. Zachariah, S. Syamkumar and B. Sasikumar, 2006. A comparative quality appraisal of exported cardamoms of India, Sri Lanka and Guatemala. Division of crop improvement and Biotechnology, Indian Institute of Spices Research, Kerala, India. Vol. 5(5).

Korikanthimath, V.S., Mulge, R. and Zachariah, T.J. (1999) Variations in essential oil constituents in high yielding selections of cardamom. *Journal of Plantation Crops 27, 230–232.*

Kung, S. C., 2008. Monitoring the Quality of Essential Oil from *Etlingera* Sp.4 (*Zingiberaceae*) By Gas Chromatography-Mass Spectrometry (GC-MS). Faculty of Chemical and Natural Resources Engineering, University of Malaysia Pahang, Malaysia.

Leela, N.K., D. Prasath and M.N. Venugopal, 2008. Essential oil composition of selected cardamom genotypes at different maturity levels. Indian Institute of Spices Research, Calicuta. *Indian Journal of Horticulture 65(3), September 2008: 366-369.*

Molla, B.A., Asfaw N., and W. Lwande, 1994. Chemical Constituents of the Essential oil of *A. corrorima* from Ethiopia. Sinet; *Ethiopian Journal of Science, 17: 145-148.*

NTFP-PFM, 2004. Baseline description of project area: Summary of participatory appraisal data at Kebele and Got level. NTFP Research and Development Project in SW Ethiopia. Student research series No. 1. Wageningen, the Netherlands.

NTFP-PFM, 2006. Local valuation of forests In South West Ethiopia. Non Timber Forest Products (NTFP) Research and Development Project in SW Ethiopia. Student Research Series No. 6. Wageningen, the Netherlands.

Parthasarathy, A. V., B. Chempakam and T. J. Zachariah, 2008. Chemistry of Spices. Indian Institute of Spices Research Calicut, Kerala, India.

Pathak, A., 2007. Cultivation of Large Cardamom in Sikkim; Facets of the Northeast, India.

Peter, K.V., 2001. Hand book of herbs and spices. Wood head Publishing Limited. Cambridge, England. Volume I: 326: 150-159.

Peter, K. V., 2004. Handbook of herbs and spices. Wood head Publishing Ltd, Cambridge England. CRC Press Boca Raton Boston New York Washington, DC. Volume II.

Peter, K. V., P. N. Ravindran, K. Nirmal Babu and M. Divakaran, 2007. Breeding of Spice Crops (Black Pepper, Cardamom, Ginger and Turmeric). Horticulture: Vegetable Science (Vegetables, Tubers & Spice Crops), Kerala Agricultural University. Pp. 16-27.

Popova, L. S., 2009. General and Applied Plant Physiology. Published by the Institute of Plant Physiology Bulgarian Academy of Sciences. *An International Journal of Plant Physiology. Volume XXXV, Issue 1–2, Pages 01–92.*

Purseglove, J.W., E.G. Brown, C.L. Green, and S.R. Robins, 1981. Spices: Volume 1 and 2. Longman group limited, London.

Raghavan, S., 2007. Spices, Seasonings, and Flavorings, 2nd ed. CRC Press Taylor and Francis Group 6000 Broken Sound Parkway NW, Suite 300 Boca Raton, London New York.

Ravindran, P.N., M. Shylaja and K. N. Bab, 2002. False cardamom, *Aframomum* sp. (Korarima cardamom: *Aframomum corrorima* (Braun). Syn., *A. melegueta* (Roscoe) Schum. (Meleguetta pepper, grains of paradise or alligator pepper). Pp. 330-340.

Rukangira, E., 2001. The African Herbal Industry: Constraints and Challenges, Erboristeria Domani.

SAS Institute Inc. 2008. SAS/STAT. 9.2 User's Guide. Cary, NC: SAS Institute Inc, USA.

Sebsebe, D. 1993. A Description of some Essential oil bearing plants in Ethiopia and their indigenous uses. *Journal of Essential Oils research, 5: 465-79.*

Silva, D. T. K., 1995. A Manual of Essential Oil Industry. United Nations Industrial Development Organization, Vienna, Austria.

Silva, L.V., D.L. Nelson, M.F.B. Drummond, L. Dufossé, and M.B.A. Glória, 2005. Comparison of hydrodistillation methods for the deodorization of turmeric. Departamento de Alimentos, Faculdade de Farmácia, Instituto de Ciências Exatas, Universidade Federal de Minas Gerais, Av. Antonio Carlos 6627, Belo Horizonte, MG, 31270-901, Brazil.

Spices Board of India, 2009. Cultivation Practices for Cardamom (*Elettaria Cardamomum Maton).* Spices Board Ministry of Commerce and Industry Government of India Cochin - 682 025. Pp. 3-36.

Stoep, V., 2010. Enhancing Competitiveness of Nepal's Large Cardamom Value Chain. SNV Netherlands Development Organization, Nepal.

Sulikeri, G. S., and S.D. Kololgi, 1977. Seed viability in Cardamom (*Elettaria cardamomum* Maton). Current Research, 6: 163-164.

Tainter, D.R., and A.T. Grenis, 2001. Spices and Seasonings. A Food Technology Handbook. 2nd Ed. Wiley-VCH. New York.

Tesfaye, A. and Sebsebe D., 2009. Ethno-botanical study of medicinal plants in Kafficho people, Southwestern Ethiopia. Proceedings of the 16th International Conference of Ethiopian Studies, Ethiopia.

Thomas, V. P., M. Sabu, and U. Gupta, 2009. Taxonomic studies on cultivars of Amomum subulatum (Zingiberaceae). Department of Botany, University of Calicut, Calicut University P. O. 673 635, Kerala and Indian Cardamom Research Institute (ICRI), Gangtok - 737 102, Sikkim, India.

UNIDO and FAO, 2005. Herbs, Spices and essential oils, Post harvest handlings in developing countries. Vienna international center, Austria.

Varadarasan, S. and A.K. Biswas, 2002. Large cardamom (*Amomum subulatum* Roxb.), Growth performance and characterization of large cardamom cultivars. Sikkim, India. 20: 299 - 305.

Wondyifraw, T. and W. Surawit, 2004. A Micropropagation Method for Korarima (*Aframomum corrorima* (Braun) Jansen). Department of Horticulture, Kasetsart University, Kampaengsaen campus, Nakhon Pathom 73140, Thailand. Research Article, Science Asia, 30: 1-7.

Wondyifraw T. E., 2004. *Invitro* propagation and polyploidy induction of Korarima (*A. corrorima* (BRAUN)JANSEN) and krawan (Amomum krervanh PIERRE). Dissertation for Doctor of Philosophy. Kasetsart University, Thailand.

Zachariah, J. T. and S. V. Korikanthimath, 2002. Harvesting and processing of cardamom, Kerala, India.

Zenebe, W., 2004. Forest resource of Ethiopia: Status, Challenges and Opportunities. Institute of Biodiversity Conservation (IBC) and German Development Cooperation (GTZ), Addis Ababa, Ethiopia.

Zenebe, W., 2002. *A. corrorima* cardamom: Unrecognized and Endangered Non-timber Forest Resources, Institute of Biodiversity Conservation. Proceedings of National Conference on Forest Resources of Ethiopia, Addis Abeba (Ethiopia). Pp. 235-245.

7. APPENDICES

Appendix Table 1. Major *A. corrorima* growing areas in Ethiopia

Region	Zone	Woreda (District)	Altitude (m.a.s.l.)
SNNPR	Kafa, Shekicho, South and North Omo (mainly Gamo Gofa), Bench-Maji, Sidama	Almost all	950 - 2500
Oromia	Illubabor, Wollega (Anfilo, Dembi-Dolo, Gimbi, Nekemet, Horo Guduru, Arjo), Jimma, Bale	Majority	1000 - 2229
Gambella	Mezgengir	Godere	500 - 1000
Amhara	East and West Gojam	Deber Markos, Kola Dega Damot, Metekel, Agew	500 - 3700

Source: Edossa,1998; Zenebe, 2004

Analysis of Variance of Fresh Capsules of *A. corrorima*

Appendix Table 2. Mean square values for weight of single fresh capsule, length and diameter of fresh *A. corrorima* capsule as affected by various harvesting stages, drying durations, drying structures and interactions

Source of Variation	Degree of Freedom	Mean Square Values		
		Weight of single fresh capsule (g)	Length of fresh capsule (cm)	Diameter of fresh capsule (cm)
DS	2	0.008 ^{ns}	0.0020 ^{ns}	0.0002 ^{ns}
HS	2	75.415***	0.4063***	0.2981***
DD	2	0.001 ^{ns}	0.0025 ^{ns}	0.0024 ^{ns}
DS*HS	4	0.001 ^{ns}	0.0001 ^{ns}	0.0007 ^{ns}
DS*DD	4	0.010^{ns}	0.0008 ^{ns}	0.0017 ^{ns}
HS*DD	4	0.005 ^{ns}	0.0002 ^{ns}	0.0018 ^{ns}
DS*HS*DD	8	0.007^{ns}	0.0008 ^{ns}	0.0013 ^{ns}
Error	54	0.018	0.0009	0.0013
CV (%)		0.573	0.502	1.029

***; very highly significant and ns =non significant at p = 0.05.

DS = Drying structure HS = Harvesting stage DD = Drying Duration

Analysis of Variance of Dried Capsules of *A. corrorima*

Appendix Table 3. Mean square values for weight of single dried capsule, dry weight recovery, moisture loss and length of dried *A. corrorima* capsule as affected by harvesting stages, drying duration, drying structures and interactions

Source of Variation	Degree of Freedom	Mean Square Values			
		Weight of single capsule (g)	Dry weight recovery (%)	Moisture loss (%)	Weight of seeds per capsule (g)
DS	2	36.489***	649.017***	649.017***	21.431***
HS	2	0.416***	203.076***	203.076***	0.223***
DD	2	4.702***	80.627***	80.627***	1.467***
DS*HS	4	0.319***	2.487***	2.487***	0.211***
DS*DD	4	0.058**	1.176**	1.176***	0.017ns
HS*DD	4	0.438***	5.640***	5.640***	0.138***
DS*HS*DD	8	0.108***	1.746***	1.746***	0.095***
Error	54	0.010	0.219	0.219	0.010
CV (%)		1.341	1.420	0.699	1.947

*, **, ***; significant, highly significant and very highly significant, respectively; ns =non significant at p = 0.05.

DS = Drying structure HS = Harvesting stage DD = Drying Duration

Appendix Table 4. Mean square values for length of dried capsule, diameter of dried capsule, weight of dried seeds per capsule, diameter of dried seed and thousand dried seed weight of *A. corrorima* as affected by harvesting stages, drying durations and drying structures and interaction

Source of Variation	Degree of Freedom	Mean Square Values			
		Length of dried capsule (cm)	Diameter of dried capsule (cm)	Diameter of dried seed (mm)	Thousand dried seed weight (g)
DS	2	5.612***	1.594***	15.026***	227.036***
HS	2	0.843***	0.639***	5.680***	8.487***
DD	2	1.838***	0.999***	3.184***	106.434***
DS*HS	4	0.014**	0.013***	0.043***	10.182***
DS*DD	4	0.044***	0.018***	0.049***	7.833***
HS*DD	4	0.012*	0.004**	0.035***	9.243***
DS*HS*DD	8	0.027***	0.003**	0.010*	2.500***
Error	54	0.002	0.0007	0.003	0.012
CV (%)		1.073	1.289	1.533	0.477

*, **, ***; significant, highly significant and very highly significant, respectively; ns =non significant at p = 0.05;

DS = Drying structure HS = Harvesting stage DD = Drying Duration

Appendix Table 5. Mean square values for dried seeds to husk ratio, dried seed to mucilage ratio, color of dried capsules and dried seeds of *A. corrorima* as affected by harvesting stages, drying durations, drying structures and interaction

Source of Variation	Degree of Freedom	Mean Square Values			
		Dried seed to husk ratio	Dried seed to mucilage ratio	Color of Dried capsules	Color of dried seeds
DS	2	1.166***	11.564***	0.668***	0.199*
HS	2	0.048*	0.439*	1.131***	1.525***
DD	2	0.379***	0.190ns	0.225***	0.236**
DS*HS	4	0.056**	0.075ns	0.060*	0.081*
DS*DD	4	0.045**	0.370***	0.008ns	0.016ns
HS*DD	4	0.054**	0.293*	0.023ns	0.016ns
DS*HS*DD	8	0.029*	0.265**	0.013ns	0.009ns
Error	54	0.011	0.062	10.743	12.094
CV (%)		3.692	3.243	10.743	12.094
				Square Root Transformed	

*, **, ***; Significant, highly significant and very highly significant, respectively; ns =non significant at p = 0.05.

DS = Drying structure HS = Harvesting stage DD = Drying Duration

Appendix Table 6. Mean square values for dry matter content, total ash content and crude fiber content of dried seeds and moisture content of dried capsules of *A. corrorima* as affected by harvesting stages, drying durations, drying structures and interaction

Source of Variation	Degree of Freedom	Mean Square Values			
		Dry matter content of seeds (%)	Total ash content of seed (%)	Crude fiber content of seeds (%)	Moisture content of capsules (%)
DS	2	47.830***	3.325***	289.567***	31.940***
HS	2	0.627*	0.136**	92.545***	0.424**
DD	2	211.297***	3.620***	52.555***	291.118***
DS*HS	4	0.851*	0.135***	2.573***	0.036ns
DS*DD	4	2.309***	0.204***	0.924*	1.638***
HS*DD	4	2.808***	0.322***	1.074*	3.368***
DS*HS*DD	8	1.016***	0.042*	1.510***	0.124*
Error	54	0.189	0.017	0.288	0.046
CV (%)		0.487	3.011	3.146	1.772

*, **, ***; Significant, highly significant and very highly significant, respectively; ns =non significant at p = 0.05.

DS = Drying structure HS = Harvesting stage DD = Drying Duration

Appendix Table 7. Mean square values for moisture content, oleoresin content and essential oil content of dried seeds and essential oil content of dried husk of *A. corrorima* as affected by harvesting stages, drying durations, drying structures and interaction

Source of Variation	Degree of Freedom	Mean Square Values			
		Moisture content of seeds (%)	Oleoresin content of seeds (%)	Essential oil content of seeds (%)	Essential oil content of husk (%)
DS	2	46.826***	17.916***	12.111***	0.266***
HS	2	1.380***	19.761***	0.542***	0.019***
DD	2	206.573***	24.099***	4.729***	0.057***
DS*HS	4	0.775***	1.167***	0.604***	0.023***
DS*DD	4	2.130***	0.258***	0.401***	0.029***
HS*DD	4	1.697***	0.525***	0.463***	0.034***
DS*HS*DD	8	0.577***	0.021**	0.336***	0.021***
Error	54	0.067	0.004	0.021	0.002
CV (%)		2.388	1.035	3.567	6.593

*, **, ***; Significant, highly significant, very highly significant, respectively; ns =non significant at p = 0.05.

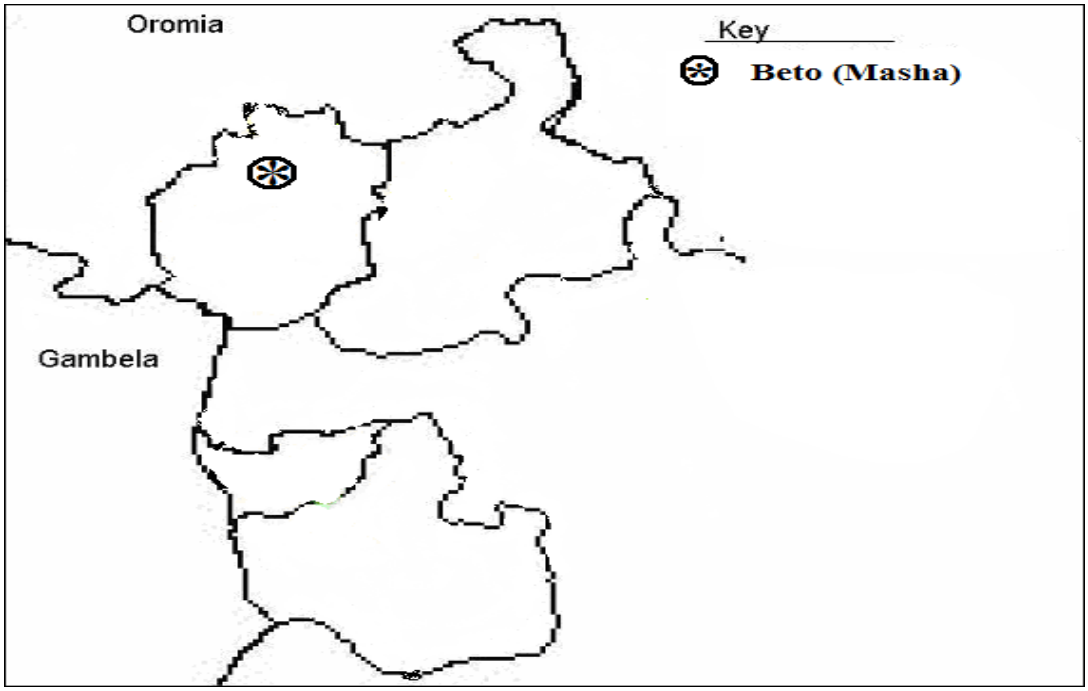
DS = Drying structure HS = Harvesting stage DD = Drying Duration

Appendix Table 8. Simple Pearson's correlation coefficients among physical and chemical quality parameters of *A. corrorima*

	WSFC	LFC	DFC	WSDC	DWR	DDC	TDSW	DSTHR	DMCS	TACDS	CFCDS	MCDC	OCDS	EODS	EODH
WSFC	1	-0.80***	-0.95***	-0.91***	-0.46***	-0.40***	-0.11	-0.10	0.04	-0.12	0.40**	-0.07	0.51***	0.13	0.15
LFC		1	0.78***	0.82***	0.31*	0.34*	0.05	-0.09	0.05	0.02	-0.31*	-0.07	-0.58***	-0.21	-0.20
DFC			1	0.95***	0.38**	0.31*	0.01	0.12	0.04	0.03	-0.30*	-0.06	-0.55***	-0.16	-0.21
WSDC				1	0.37**	0.32*	0.02	0.15	0.06	0.02	-0.29*	-0.08	-0.56***	-0.17	-0.22*
DWR					1	0.89***	0.85***	0.41***	-0.62***	0.78***	-0.89***	0.54***	0.38***	0.63***	0.56***
DDC						1	0.82***	0.09	-0.76***	0.80***	-0.91***	0.72***	0.43***	0.52***	0.50***
TDSW							1	0.23*	-0.83***	0.89***	-0.76***	0.75***	0.71***	0.74***	0.74***
DSTHR								1	0.13	0.05	-0.14	-0.20	0.03	0.31*	0.15
DMCS									1	-0.87***	0.61***	-0.96***	-0.75***	-0.57***	-0.58***
TACDS										1	-0.71***	0.82***	0.68***	0.64***	0.62***
CFCDS											1	-0.54***	-0.35***	-0.51***	-0.49***
MCDC												1	0.73***	0.51***	0.49***
OCDS													1	0.71***	0.70***
EODS														1	0.90***
EODH															1

*, **, ***; Significant, highly significant and very highly significant, respectively at p = 0.05 according to LSD test.

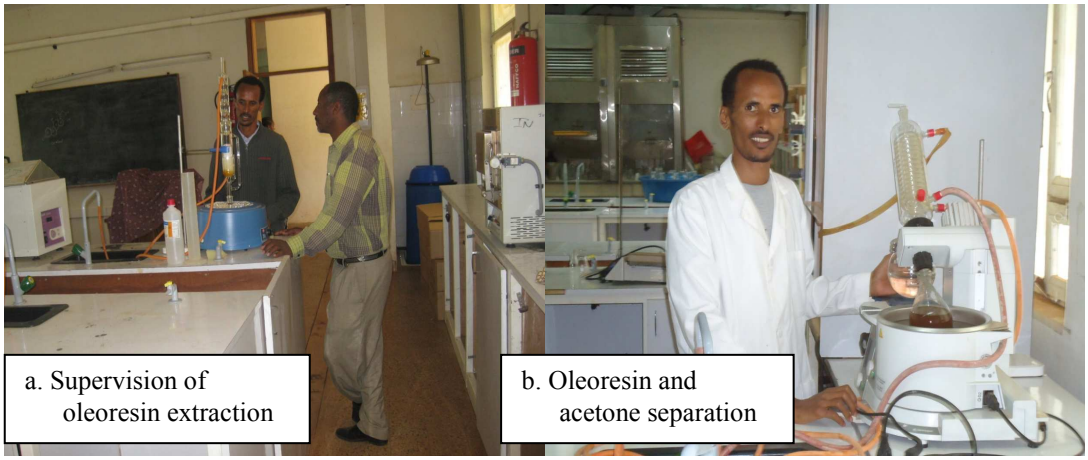
WSFC, LFC, DFC, WSDC, PDWR, DDC, TDSW, DSTHR, DMCS, TACDS, CFCDS, MCDC, OCDS, EODS and EODH: Weight of single fresh capsule, length of fresh capsule, diameter of fresh capsule, weight of single dried capsule, dry weight recovery, diameter of dried capsule, thousand dried seed weight, dried seed to husk ratio, dry matter content of seeds, total ash content of dried seeds, crude fiber content of dried seeds, moisture content of dried capsule, oleoresin content off dried seeds, essential oil content of dried seeds and essential oil content of dried husk, respectively.



Appendix Figure 1. Map of Sheka Zone

Appendix Figure 2. *Aframomum corrorima* capsules

Appendix Figure 3. Essential oil and oleoresin extraction

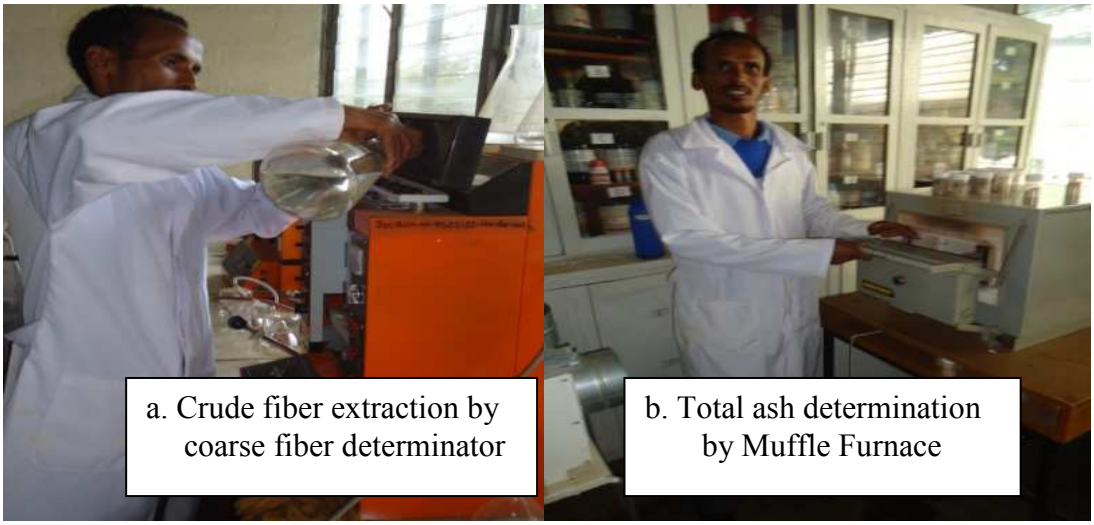


Appendix Figure 4. Supervision during oleoresin extraction and separation

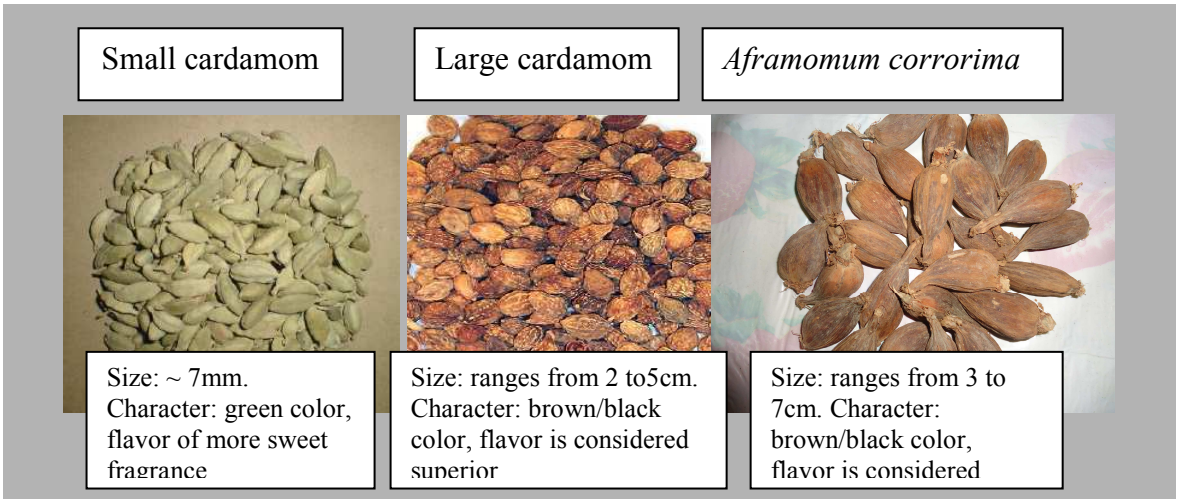
Appendix Figure 5. Acetone extract oleoresin of *A. corrorima* seeds

Appendix Figure 6. Separation of essential oil by Separator Funnel

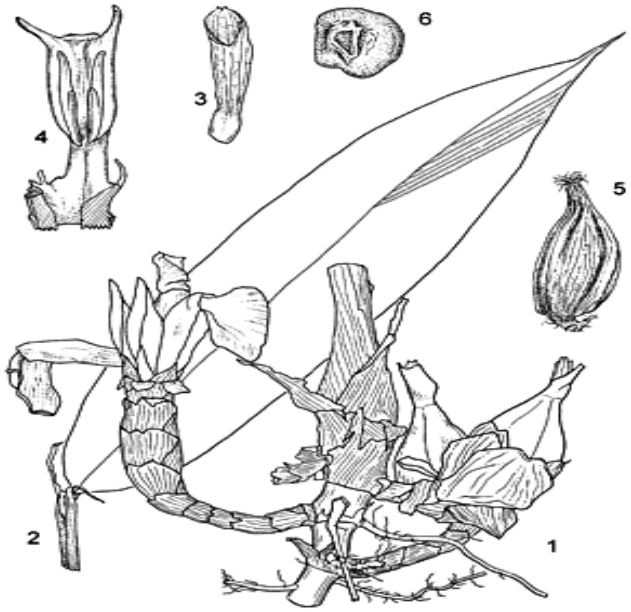
Appendix Figure 7. Essential oil of *A. corrorima* seeds



Appendix Figure 8. Crude fiber and total ash determination

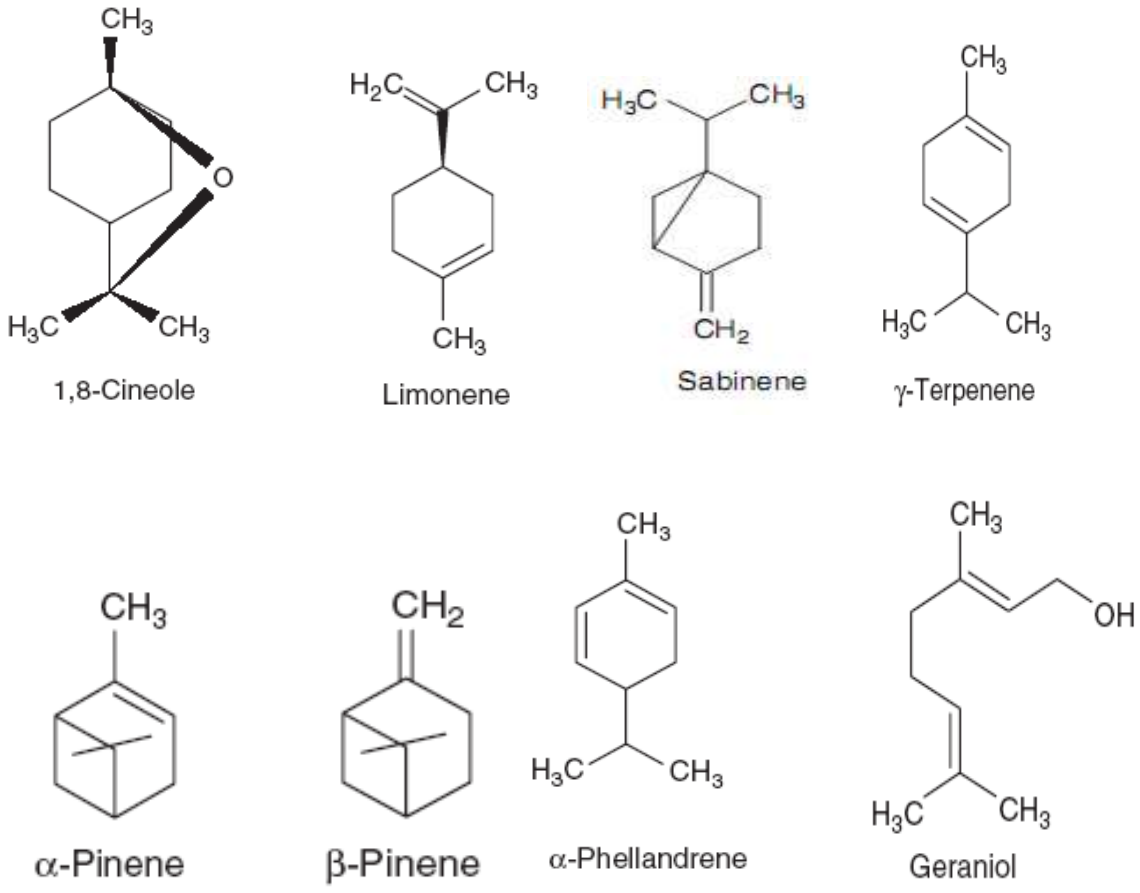


Appendix Figure 9. Small and large cardamoms and *A. corrorima* dried capsules



1=part of rhizome with flowers and fruits; 2= leaf; 3=calyx; 4=anther; 5=dried fruit; 6=dried seed

Appendix Figure 10. Anatomy and Morphology of *A. corrorima*



Appendix Figure 11. Major chemical constituents of *A. corrorima* essential oil