BROADENING UTILISATION OF COCONUT KERNEL THROUGH PRODUCTION OF COCONUT ICE CREAM

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Broadening Utilisation of Coconut Kernel through Production of Coconut Ice Cream

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DECLARATION

This thesis is my original work and has not been presented for a degree in any other University.

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This Thesis has been submitted for examination with our approval as the University supervisors:

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DEDICATION

This research is dedicated to my wife, Mary, and son, Barry Clinton, for their patience, understanding, encouragement, and support during the study period.

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ABSTRACT

The coconut tree (*Cocos nucifera*) is widely referred as the "tree of life" for its important role in the 10 million livelihoods from over 90 countries globally. In Kenya, the coconut sub-sector is valued at KES 25 billion, yet only 65% is utilised depriving the country the necessary revenue, which is pivotal in achieving sustainable development. This study was aimed at exploring coconut utilization through value addition of coconut kernel to produce coconut ice cream at the coastal counties of Kilifi and Kwale. A structured interview with lead questions was used in knowing the coconut varieties grown at the coastal part of Kenya, food-based products made from the coconut kernel, and the challenges facing enterprises in the coconut value chain. This was followed by random sampling of coconut fruits, which were then de-husked and de-shelled in determining coconut fruit composition Subsequently, colour analysis of the coconut kernel was done using hunter lab colour difference meter. Additionally, proximate analysis and fatty acid profile of coconut kernel was caried out as guided by AOAC (2000) methods and base-catalysed transesterification respectively. Finally, coconut milk was extracted to make coconut ice cream followed by sensory evaluation. The field survey revealed that four varieties of coconut were evident: East African Tall (Green) -, East African Tall (Yellow), Dwarf (Yellow), and East African Short. limited coconut-kernel based products was evidenced by only six products (virgin coconut oil, desiccated coconut, copra oil, coconut milk, coconut cream, and coconut flour). This was attributed to challenges such as obsolete technology and machines, insufficient capital for business expansion, limited marketing, immature nuts being used, cracking of nuts during storage, and insufficient research. based on the de-husked coconut fruit, coconut kernel was the highest in comparison to shell and water across the coconut varieties. Regarding colour, generally high L* (light vs. dark) values (85.34 - 93.35±1.64) and low a* (red vs. green) values (0.51-0.81) and b* (yellow versus blue) values (1.53-2.20) values, justifying the milky-white colouration of the kernel. Notably, proximate analysis revealed high crude fat (35.01-38.28%) across the varieties. Fatty acid profile revealed that the highest fatty acid in composition was lauric (45.91-50.72%). Between the developed ice cream, pure coconut flavour was the most preferred. The Kenyan coconut sub-sector is faced by challenges leading to limited value addition and, therefore, development of coconut ice cream is timely. Most of the coconut oil extract was saturated (91%), indicating stability for storage and suitability for use in ketogenic diets.

CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

Coconut (*Cocos nucifera* L.), as a member of the *Palmacea* family, grows in the tropics and is generally referred to as a coconut palm (Patil & Benjakul, 2018). The coconut palm is commonly termed as the "tree of life," "heavenly tree," "tree of abundance," or "nature's supermarket" due to its important role as a direct source of materials, nutrition, and income to over 10 million households in about 90 countries worldwide (Omar & Fatah, 2020). Indeed, coconut palm surpasses any other tree due to its robust utility, making it the most extensively grown worldwide. Coconut palm provides the people living in the tropics with basic necessities like food, shelter, drink, medicine, fuel, and decorative materials among others. In particular, the juice from the inflorescence has about 15% sugar, which is critical in its use to make palm-wine in addition to being drunk (Ahuja, Ahuja, & Ahuja, 2014). Coconut water, the clear liquid found in both young coconuts of between 6-10 months old and mature nuts, is refreshing.

The coconut milk can be squeezed out of the meat (endosperm) (Patil & Benjakul, 2018). Fully ripened coconuts (after 11-12 months) yields kernel, which can be eaten in its raw form in addition to processing. Coconut oil results pressing the copra (dried coconut meat) or coconut milk. The coconut oil has medicinal benefits due to being rich in lauric acid, a medium chain fatty acid, well known for its anti-bacterial, anti-fungal, and antiviral properties (DebMandal & Mandal, 2011; Pharm, 2016). The hard-outer shell of coconut is used in making charcoal (Ahuja et al., 2014). Coconut fibres find their use in the upholstery in making ropes, peat, or mulching material (Ahuja et al., 2014). Moreover, the wood and the leaves are utilised as building materials (Ahuja et al., 2014), and the list is endless. Majority of coconut-based food products are generated from the kernel/meat, with the most known ones globally being coconut oil, coconut milk, and desiccated coconut (Patil & Benjakul, 2018).

In the Kenyan context, the role played by coconut sub-sector cannot be underestimated as it supports more than 80% of coastal farm households (about 2.4 million people), who directly or indirectly depend on it for food, income, and employment (Agwanda et al., 2010). According to the national coconut survey report of 2013 by Kenya Coconut Development Authority, now known as Nuts/Oil Crops Directorate, coconut sub-sector approximately supports more than 100,00 farmers contributing over 1.5% of the agricultural GDP and 0.4% of the national GDP. The value chain analysis of coconut sub-sector in 2015 by Agriculture and Food Authority (AFA)-Nuts/Oil Crops Directorate (NOCD) states the sub-sector has a potential of creating more than 10,000 jobs nationally, contributing to the expected KES 25 billion annually to the GDP. Despite this great potential, coconut palm is grown by small holder farms at the coast, whereby it is one of the main cash and food crop giving support to livelihoods of people in counties such as Kwale, Kilifi, Tana River, Lamu, Mombasa, and Taita-Taveta.

The coconut survey by the Kenya Coconut Development Authority- KCDA (2013) revealed the following statistics: wine (59.0%), mature nuts (22.0%), makuti (14.2%), immature nuts (2.1%), tree trunks (1.5%), brooms (1.0%), and seedlings (0.1%). AFA-NOCD (2015), however, indicated that the following products as existing: coco peat, coconut milk, coir fibre, copra, copra oil, copra cake, desiccated coconut, Nata de coco, virgin coconut oil, makuti, and brooms. Such diversification in the coconut sub-sector value addition is attributed to the efforts by KCDA (now NOCD) and partners in addition to the recognition of the crop's potential in generating incomes in the production areas (Kenyan coast). In fact, notable increase in the value of coconut exports has been on an increasing trend since 2009, for instance, desiccated coconut's export value at 2009 was KES 17,493,106, whereas at 2012, it was KES 20,588,594 (AFA-NOCD, 2015). Coconut exports are mainly to countries such as Tanzania, Uganda, Djibouti, Pakistan, Mauritius, Yemen, Netherlands, Canada, and United States of America (KCDA, 2013). Nonetheless, Kenya as a country import higher than it exports coconut-based products. For example, in 2011, the value of coconut exports amounted to KES 39.8 million, whereas the imports were KES 825.1 million, creating a net import or imbalanced payment amounting to KES 785 million. However, according to Export Promotion Council's data, the new imports for amounted to KES 1 billion (AFA-NOCD, 2015). To this end, it is clear that Kenyan economy has been losing between KES 750 million and 1 billion yearly since 2011 simply due to lack of value addition of coconut raw materials. Therefore, this study is timely in broadening the utilisation of coconut kernel through production of coconut ice cream in an attempt to limit importation while increasing exportation of coconut food-based products.

1.2 Problem Statement

Regarding production, the Kenyan coconut sub-sector is valued at KES 25 billion, yet the market under exploitation is approximated at 65%, depriving the country the necessary revenue, which is pivotal in achieving sustainable development (AFA-NOCD, 2015). In the words of Muhammed et al. (2012), the Kenyan coconut sector "is depicted as the sleeping giant" (p. 152). This is against the backdrop of many economic coconut uses, reinforcing the existence of very little interpositions put in place to optimise the coconut subsector's enormous economic potential, and maximise returns. The underutilisation of coconut is evident in the high poverty index in the coastal counties of Lamu, Tana River, Kwale and Kilifi (KNBS & SID, 2013), yet coconut can be a resource for improved livelihood.

In relation to research, studies on the composition of coconut kernel are either old or incomplete in their scope (i.e., lacking some constituents). For instance, proximate analysis is "saturated" with old studies (Dendy & Timmins, 1973; Grimwood, 1975; Balachandran et al., 1985; Chakrabotty, 1985; Kwon et al., 1996). Recent studies lack analysis of fibre, carbohydrate, and protein (Appaiah et al., 2015; Patil et al., 2017). Moreover, in relation to fatty acid profile, majority of studies omit analysis of either caproic acid (C6:0) or arachidic acid (C20:0) (Laureles et al., 2002; Azeez, 2007; Ghosh et al., 2014; Pham, 2016; Boateng et al., 2016) all of which are important in determining the nutritional and health benefits of the oil. Locally, there is little or no research on the physical and chemical properties of the coconut kernel, and generally on the coconut fruit (Muhammed et al., 2012).

1.3 Justification

Coconut is a priority crop for NOCD given its potential of increasing the country's revenue and achieving sustainable development upon full exploitation of the sub-sector, which is valued at KES 25 billion. Coconut, especially coconut kernel, can be used to make a number of value-added products, which are stable for storage and suitability for use in ketogenic diets given the saturation level of the oil content. By applying strategic interventions such as value addition linkages, more than 100,000 farmers can be supported to contribute to over 1.5% of the agricultural GDP and 0.4% of the national GDP (KCDA, 2014). In addition, coastal counties of Kwale and Kilifi, which are poverty-stricken, can have their citizens' livelihoods improved through commercially viable coconut value-added products like coconut ice cream.

1.4 Research Objectives

1.4.1 Main Objective

The aim of this study is to explore coconut kernel utilisation by developing coconut ice cream.

1.4.2 Specific Objectives

In achieving the main objective, the study will be guided by the following specific objectives:

1. To determine the current status of utilisation of coconut and its value-added products at the Kenyan coast.
2. To determine the physical-chemical properties of coconut kernel from different coconut varieties.

3. To explore possibilities for utilisation of coconut kernel in ice-cream production.

1.5 Research Questions

This research seeks to answer the following questions:

1. What is the current status of utilisation of coconut and its value-added products at the Kenyan Coast?
2. What are the physical-chemical properties of coconut kernel from different coconut varieties from the Kenyan coast?
3. What is the possibility of producing ice cream from the coconut kernel?

1.6 Research Hypothesis

The following research hypotheses were tested by the study:

$H_0$1: Different varieties of coconut do not have kernel with varied physical-chemical properties.

$H_0$2: There is no difference in flavour of the developed two forms of coconut ice cream.

CHAPTER TWO

LITERATURE REVIEW

2.1 Overview of Coconut Sub-Sector Globally

Globally, coconut is grown over an area of about 12.23 million hectares in 93 countries supporting a sector valued at $6 billion (Patil & Benjakul, 2018). The importance of coconut palm economically cannot be over-emphasized especially in Pacific and Asian regions where the crop is grown on a large scale. Asia tops in the world as the major coconut producer with 90% of the total production emanates from Indonesia, India, Philippines, Sri-Lanka, and Thailand (Patil & Benjakul, 2018). Approximately, 70% of coconuts are consumed locally, and more than half are eaten fresh worldwide (Patil & Benjakul, 2018). Though in the past productivity of coconut was at standstill globally, especially between 2003 and 2008, there has been an increase in the production of coconut with the Asian and Pacific Coconut Community (APCC) countries being on the lead (Patil et al., 2017). However, in spite of the size and wealth of the global coconut sub-sector, majority of the coconut growers are among the poorest in the society (Patil & Benjakul, 2018).

2.2 Overview of the Coconut Sub-Sector in Kenya

2.2.1 Potential

Kenya has a promising coconut sub-sector with 9,907,117 million coconut trees, which according to the last coconut survey, supporting the lives of over 100,194 farmers and contributing to about 1.5% of the agricultural GDP and 0.4% of the national GDP (KCDA, 2014). Additionally, progress has been realised in the value chain addition by including coconut food-based products (virgin coconut oil, desiccated coconut, coconut milk, coconut cream, and copra oil) to the raw and non-food products (mature nuts, makuti, immature nuts, tree trunks, brooms, and seedlings) (KCDA, 2013; AFA-NOCD, 2015). This has led to bridging the gap of coconut utilisation from 24% to 65% (AFA-

NOCD, 2015). Further, Agwanda et al. (2010) and Muhammed et al. (2012) argue that the coconut production at the Kenyan coastal region has the capacity of substituting 30% of the total edible oil imports.

2.2.2 Challenges

The Kenyan coconut sub-sector is valued at KES 25 billion, yet the utilisation is at 65%, making 35% to go to waste. This under-utilisation is attributed to challenges affecting the players involved including farmers, seedling suppliers, processors, and traders. According to Muhammed et al. (2012), the Kenyan coconut sub-sector is not realising its full potential due to lack of incentives and insufficient policy framework by the government. In fact, the coconut varieties in Kenyan are limited due to failure of propagation to produce hybrids (KCDA, 2013). The challenges are summarised in the Table 1 below.

Table 2.1: Challenges facing the Kenyan coconut sub-sector

Player	Challenge	Reference
Farmers, seedling suppliers, processors, and traders	• Production or operations • Marketing • Finance • Business management	KCDA (2013)
-	• Large population of senile trees • Pest and diseases • Low levels of value addition • Low private sector investment • Lack of access to credit • Lack of sustainable marketing structures • Lack of appropriate and affordable technologies • Lack of affordable financial credit	AFA-NOCD (2015)

2.3 Coconut Varieties

Generally, there are three varieties of coconut grown globally, and they include tall coconut varieties, dwarf coconut varieties, and hybrid varieties (Ekanayake, Perera. & Everard, 2010). To begin with, the tall coconut varieties are the most common with two known cultivars expansively grown being the West Coast Tall and East Coast Tall varieties (Ekanayake et al., 2010). These varieties averagely live up to between 80 and 90 years with the capability of growing to an altitude of 3,000 ft. above the sea level (Ekanayake et al., 2010). Further, the tall variety can grow to a height of between 15 and 18m, and sometimes can exceed this range (Ekanayake et al., 2010). They also thrive under various soil conditions involving littoral sands and red loams in addition to being resistant to pest and diseases. In general, the nuts from the tall coconut varieties are medium-sized, and have different shades of colours including brown, yellow, orange, and green (Ekanayake et al., 2010). The tall coconut varieties exhibit cross-pollination and, therefore, they share their genetic materials with several others leading to increased variation in the coconut characteristics.

On the other hand, the dwarf coconut varieties are shorter than the tall varieties growing to an average height of between 20 and 60ft (Ekanayake et al., 2010). They have a lifespan of 40 to 50 years and start bearing coconut fruit earlier as compared to the tall varieties (Ekanayake et al., 2010). The nuts of the dwarf varieties are small-sized and round in shape. However, the nuts are higher in number in comparison to those produced by the tall coconut varieties. Additionally, the trees are highly vulnerable to drought, and characteristically produce green-, yellow-, and orange-coloured coconuts (Ekanayake et al., 2010). In contrast in tall varieties, the dwarf varieties self-pollinate and, thus, they have limited variations. The hybrid varieties are two morphological forms produced from both the tall and dwarf varieties in two different ways. First, a tall female parent variety and a dwarf male parent variety are crossed. Second, a dwarf female parent variety and a tall male parent variety are crossed. The resulting hybrid varieties showcase early flowering and excellent produce than the parent varieties. Moreover, they perform exceptionally well in the presence of good growing conditions inclusive of nutrient and irrigation management (Ekanayake et al., 2010).

2.4 Physical and Chemical Properties of Coconut

The edible coconut products are predominantly obtained from the meat (solid endosperm) and water (liquid endosperm) (DebMandal & Mandal, 2011). Generally, the entire coconut fruit takes a year to mature with various developmental stages: the husk and shell, first, grow followed by enlargement of embryosac cavity; this cavity is then filled with liquid; the husk and shell becomes thicker after 4 months; the meat starts to form against the inner wall of the cavity after 6 months with the first layer being thin and gelatinous; after 8 months, the soft white endocarp turns dark brown and becomes hard; and lastly the fruit becomes mature within 1 year (12 months) (Patil & Benjakul, 2018).

The mature coconut fruit contains 25% water, 28% meat, 12% shell, and 35% husk in addition to weighing between 3 and 4 kilograms (DebMandal & Mandal, 2011). In obtaining the edible portion, the shell of the coconut is removed after eliminating the husk, followed by pairing and water drainage. The meat/kernel is then manually collected and grated to yield other products. The composition of the mature coconut kernel is dependent on variety, nut maturity, geographical location, and cultural practices (Seriphan & Benjakul, 2015). Further, Patil et al. (2017) claim that different stages of maturity impact on the chemical composition of coconut kernel and milk. Proximate compositions of mature coconut kernel by various authors are listed in Table 2 below.

Table 2.2: Proximate composition of coconut (mature) kernel

Composition (%)						
Moisture	Crude Fat	Carbohydrate	Crude Protein	Crude Fibre	Ash	Reference
44.0	38.1	9.9	3.6	3.1	1.3	Dendy & Timmins (1973)
42-48	36.0	7.20	4.0	2.0	-	Grimwood (1975)
35.37	44.01	6.57	5.5	3.05	0.77	Balachandran et al. (1985)
36.0	41.5	16.9	4.5	-	1.1	Chakrabotty (1985)
40.9	35.2	-	3.8	-	-	Kwon et al. (1996)
7.35*	42.3*	31.7*	10.2*	7.42*	1.01*	Nnorom et al. (2013)
3.94*	71.62*	6.90*	8.80*	7.15*	1.59*	Ghosh et al. (2014) *
61.07	20.86	13.05	3.95	-	1.14	Patil et al. (2017)

*Proximate determination is on dry weight basis.

Regarding the colour of coconut meat (not considering the testa), Ghosh et al. (2014) and Patil et al. (2017) present it as milky- white. Additionally, the profile of coconut oil according to researchers, as shown in Table 3, showcases lauric acid as the highest concentration and caproic acid and arachidic acid as the lowest concentrations.

Table 2.3: Fatty acid profile of coconut oil

Fatty Acid Profile (%)										
Caproic (6:0)	**Caprylic (8:0)**	**Capric (10:0)**	**Lauric (12:0)**	**Myristic (14:0)**	**Palmitic (16:0)**	**Stearic (18:0)**	**Oleic (18:1)**	**Linoleic (18:2)**	**Arachidic (20:0)**	**Reference**
0.41-0.53	6.26-8.59	5.65-7.01	50.50-47.48	17.73-19.61	7.39- 9.81	5.17- 7.63	-	2.30- 4.07	-	Laureles et al. (2002)
-	1.32- 3.08	2.48-4.01	36.99-42.86	20.69-25.04	11.27-15.17	11.36-19.18	-	-	-	Azeez (2007)
0.08- 0.49	2.77-7.21	3.46-5.94	42.-52	18.12-23.05	7.59-12.99	2.45-4.07	4.92-10.86	0.14-2.80	0.02 -0.19	Kumar (2011)
0.08	0.13	3.50	51.88	21.86	9.12	1.90	8.82	2.71	-	Ghosh et al. (2014)
-	2.4	4.4	44.5	18.6	12.0	4.8	11.0	2.2	-	Pham (2016)
-	8	7	49	8	8	2	6	2		Boateng et al. (2016)
0.10-0.95	4-10	4-8	45-56	16-21	7.5-10.2	2-4	4.5-10	0.7-2.5		*APCC Standard

*APCC – Asian and Pacific Coconut Community

2.5 Uses of Coconut Kernel

The uses of coconut kernel are numerous, and they include the following:

2.5.1 Coconut milk and Cream

Coconut milk is not actually found inside the coconut but is made from grated coconut meat and added water. It is a traditional homemade drink in many tropical countries. Coconut milk is highly nutritious; it is rich in fibre, minerals and vitamins B, C and E as well as healthy fatty acids (medium chain triglyceride) (Mathavan, 2009). It is an oil-water emulsion generated from the coconut meat's aqueous extract. The coconut meat is subjected to disintegration through the use of rotary wedge cutter followed by pressing and squeezing with hot water to maximally extract milk from the kernel. After extraction of milk, filtration is done to remove the solids followed by pasteurization for elimination of microorganisms. Increase in water temperature during the extraction process does not impart a positive effect, but the repeated extraction does increase the milk quantity by 11.01% (Patil & Benjakul, 2018). Coconut milk has a delicious creamy taste and can be consumed on its own as well as in smoothies and many dishes such as curries, soups and desserts. It's one of the most versatile coconut products. It is a great replacement for recipes that traditionally call for cow's milk and very popular among vegans and people who follow a lactose-free diet (Patil & Benjakul, 2018). During the production of coconut milk, the liquid will separate into a cream that can be skimmed off and used for another coconut product; coconut cream. It looks similar to coconut milk but is thicker and creamier; perfect for recipes that require a rich consistency.

2.5.2 Copra oil

Coconut oil extracted from either fresh or dried coconut meat. Fresh coconut meat is used to produce virgin coconut oil, while dried coconut meat (copra) is used for crude and refined coconut oil (Ahuja et al., 2014). Coconut oil has higher amounts of saturated fat leading to slow oxidation (resistant to rancidity), hence, longer shelf-life of two years without spoiling (Pham, 2016). Arguably, certain fatty acids and their derivatives present in coconut oil have capability of inactivating different microorganisms like bacteria, fungi, yeast, and viruses (Loomba & Jothi, 2013). Generally, in most cases coconut oil is obtained by mechanical methods of extraction. In particular, dry extraction method involves pressing of copra (dried kernel) in a screw press/hydraulic press to extract the oil by breaking the kernel's oil cells. After the extraction process, the oil and cake are separated by filtration. Cake is useful as substrates for the production of alpha amylase as aided by *Aspergillus oryzae* species (Ramachandran et al., 2004).

2.5.3 Virgin coconut oil

Virgin coconut oil has been regarded as the mother of all oils. Virgin coconut oil (VCO) is rich in vitamin E, minerals, other vitamins, anti-oxidant, and medium chain fatty acids, especially lauric acid. Approximately, 50% of lauric acid in the VCO improves immunity of human beings (DebMandal & Mandal, 2011). Generally, VCO is produced through the wet method. VCO is not subjected to heat treatment (high temperatures), solvents, or refining process and, thus, the final product preserves the fresh scent and taste. VCO can be produced from coconut milk or fresh meat. From the meat, it is extracted by grating, drying, and pressing. From the coconut milk, grating, mixing with water, and centrifuging at high speed are done. Alternatively, the milk can be fermented for a period of between 36 and 48 hours followed by the removal of the oil, and heating of the cream to remove any remaining oil (Villarino et al., 2007). This method of oil extraction is cheap since it limits the usage of solvent, which considerably reduce energy requirements and investment cost. VCO is very suitable for all methods of cooking, baking and frying, in desserts and in snacks because it compliments both savoury and sweet dishes. It contains a lot of healthy saturated fat, which makes it the most heat-stable and healthy fat to cook with. It has a melting point of 24°C (Punchihedw & Arancon, 2012). Coconut oil is probably the most famous of all coconut products.

2.5.4 Desiccated Coconut

Desiccated coconut is generated from the dried, and shredded after separation from the brown testa. The fresh matured coconuts are subjected to de-husking and deshelling to obtain the kernel, which is then disintegrated into smaller sizes. The resulting coconut flakes are blanched in the steam for approximately 20 minutes to purposely reduce microorganisms (Madhiyanon et al., 2009). They are then dried in hot air at a temperature range of between 80^0C and 90^0C for a period of 10 hours to attain the moisture content of 3% (Madhiyanon et al., 2009). The desiccated coconut obtained is easy to transport and has more shelf-life. It is used mostly in confectionaries, puddings, baking, and ice creams.

2.5.5 Coconut Flour

Dehydrated or air/oven dried coconut meat is blended to flour. The desiccated coconut can be grinded to form coconut flour. Coconut flour makes a great gluten-free flour and can replace regular wheat or other grain flours in most recipes. It has a mildly sweet taste, but is not dominant, so it can also be used in savoury dishes. Coconut flour has the highest fibre content of all flours (48%) and is low in carbohydrates (Punchihedw & Arancon, 2012). Because it is so rich in fibre, it absorbs more liquid and, therefore, one need to use a different ratio with regular flour: roughly 1/4 cup of coconut flour for 1 cup of regular flour (Punchihedw & Arancon, 2012).

2.5.6 Coconut Yoghurt

The fermentation of a cow's milk by the aid of lactic acid bacteria like *Lactobacillus debrueckii* and *Streptococcus thermophilus* leads to the production of yoghurt. Similarly, yoghurt can be made from the coconut milk for the consumption by lactose intolerant people. According to Yaakob et al. (2012), 1 litre of coconut milk after preheating to a temperature of 90^0C for 3 minutes, is cooled to 40^0C. After this, 3% of the inoculum is mixed with the cooled coconut milk and incubated for 8 hours at 37^0C then stored at

4^0C. Coconut milk and soy milk in equal measure (each 50%) have been combined to successfully produce soy-coconut yoghurt (Mathavan, 2009). Additionally, studies have shown that yoghurt from the coconut-cow milk and that from skimmed cow milk do not manifest significant difference in sensory attributes and, therefore, coconut milk and cow milk can be used alongside one another to produce an affordable and acceptable yoghurt (Sanful, 2009).

2.5.7 Coconut Butter

Coconut flakes are mixed optionally with some added coconut oil to make creamy coconut butter (Mathavan, 2009). It can be used as a vegan, dairy free butter replacement, and nut-free nut butter, as a base for desserts such as fudge and for frosting.

2.5.8 Coconut Protein Powder

Coconut protein powder is recoverable from the wet processing of coconut waste during the VCO production. To begin with, the coconut milk is subjected to protease treatment (1 litre of coconut milk is subjected to 100 tyrosine units) for a period of 2 hours to purposely destabilise the coconut milk (water-oil) emulsion (Naik et al., 2012). Then, centrifugation is done at 7000 revolutions per minute (rpm) leading to three products: skim milk, cream, and solid protein. Consequently, the solid protein and skim milk are mixed thoroughly in the ratio of 2:8 (weight/volume), subjected to homogenization, and placed into the spray dryer. The resulting protein powder is gathered via a cyclone separator, and consists of 33% protein content and 3% fat. The protein powder is characterised by good emulsifying property as compared to bovine skim milk protein and more water retention capability as well as swelling capacity (Naik et al., 2012).

2.5.9 Coconut Jam

Jam (intermediate moisture food product) is generated from the residual coconut pulp after removal of water. Young-tender coconuts are widely used. In the preparation, the pulp is boiled with sugar, acid, pectin, preservative, colouring, and flavouring material, to a reasonable consistency (Chauhan et al., 2013). After attaining the total soluble solids of 60^0 Brix, 1.25% pectin and 0.5% citric acid are added to the boiling pulp and continuous stirring done until the mixture attains between 67 and 68^0 Brix (Chauhan et al., 2013). Finally, the hot mixture is fed into sterile glass bottles and cooled to room temperature. The product can stay for 6 months at room temperature before becoming stale. Alternatively, combining coconut pulp to pineapple pulp in the ratio of 75:25 results in a jam with good textural and organoleptic features (Chauhan et al., 2013).

2.5.10 Coconut Syrup

Coconut syrup, a free flowing and translucent nutty flavoured liquid, is a product of coconut milk. During the preparation, coconut milk and sugar in equal proportions are mixed, and 0.05% citric acid or 0.25% sodium phosphate added (Purnomo, 2007). The mixture is then heated to attain between 65 and 68^0 Brix (Purnomo, 2007). The hot syrup is then filled into lacquered tin cans and cooled under water. This product can be drunk instantly upon mixing with water, and also used as a bread spread.

2.5.11 Coconut Candy

Coconut candy can be made either from coconut milk of coconut cream. Sugar and malt syrup are then added in the desired proportions (Nkemakonam, 2018). Further, the mixture is heated under high temperatures until caramelisation (Nkemakonam, 2018). After the achievement of thick consistency, the mass is then transferred into a mould followed by cooling. The candy is eventually cut into desired sizes and shapes, and wrapping done.

2.5.12 Coconut Honey

Coconut honey as a free-flowing viscous liquid, is similar to coconut syrup, however, it is less nutty (flavour) and less creamy. In its preparation, skimmed coconut milk, refined sugar, and glucose in the ration of 1:0.5:0.5 are blended together and sodium alginate added a stabiliser (Mankar et al., 2018). Coconut cream can be added to improve the product's flavour. The resulting mixture is subjected to heating for approximately 15 minutes, homogenised, and then cooked to reach 75^0 Brix (Mankar et al., 2018). The eventual product has a golden colour with thick consistency and nutty flavour. Coconut honey can form the base in the manufacture of soft drinks.

2.5.13 Coconut Ice Cream

Ice cream, as a very complex food matrix, consists of fat, protein, sugar, minerals, and air among others with various interfaces (Frost et al., 2005). An ideal ice cream contains between 10 and 16% milk fat, 9 and 12 milk solids not fat (MSNT), 12 and 16% sweeteners, 0.2 and 0.5% stabilizer-emulsifier blend, and 55 and 64 water from the milk and other ingredients (Frost et Sal., 2005). Instead of using cow milk, coconut ice cream uses coconut milk as the base ingredient. Other ingredients include whipping cream, MSNT, sugar, stabilizer, flavour, and colour. Freezing the ice cream mix in the ice-cream freezer incorporates air with the best overrun being over 70% (Jayasundera & Fernando, 2014). Nonetheless, care should be taken to graininess in the ice cream by avoiding crystallization of water droplets into ice. Coconut ice cream is not present in the Kenyan market (AFA-NOCD, 2015).

2.6 Summary

Evidently, studies on the proximate composition of coconut kernel are, first, very old (Dendy & Timmins, 1973; Grimwood, 1975; Balachandran et al., 1985; Chakrabotty, 1985; Kwon et al., 1996), and secondly, lack analysis of fibre, carbohydrate, and protein (Appaiah et al., 2015; Patil et al., 2017). Regarding fatty acid profile, majority of studies omit analysis of either caproic acid (C6:0) or arachidic acid (C20:0) (Laureles et al., 2002; Azeez, 2007; Ghosh et al., 2014; Pham, 2016; Boateng et al., 2016). In the Kenyan context, the coconut sub-sector is depicted as a sleeping giant: the Kenyan coconut sub-sector is valued at KES 25 billion, yet the market under exploitation is approximated at 65% and, therefore, urgent need of value addition linkages.

CHAPTER THREE

MATERIAL AND METHODS

3.1 Field Survey

A field survey was carried out at the Kenyan coastal counties of Kilifi and Kwale as presented in Figure 1. Using simple random sampling, a total of 6 enterprises were sampled, out which 2 were major processors (Kentaste and Amor Cocco), three small and medium enterprises (Coco Vita, Mama Sonje, and Ramisi Coconut Processors), and 1 farmer (Bazi Farm Enterprises). In addition, the AFA-NOCD office at Mombasa was also visited. The sample size was small because of the limited number of enterprises involved in the production of food-based coconut products in Kilifi and Kwale counties. Majorly, the survey was to make known the coconut varieties grown at the Kenyan coast, the products made from the coconut kernel with the aim of identifying gaps in the value chain, and the challenges faced by the enterprises in the coconut value chain. To this end, a structured interview with leading questions was targeted at the study sample as presented in Appendix 1. Each interview session took 40 minutes.

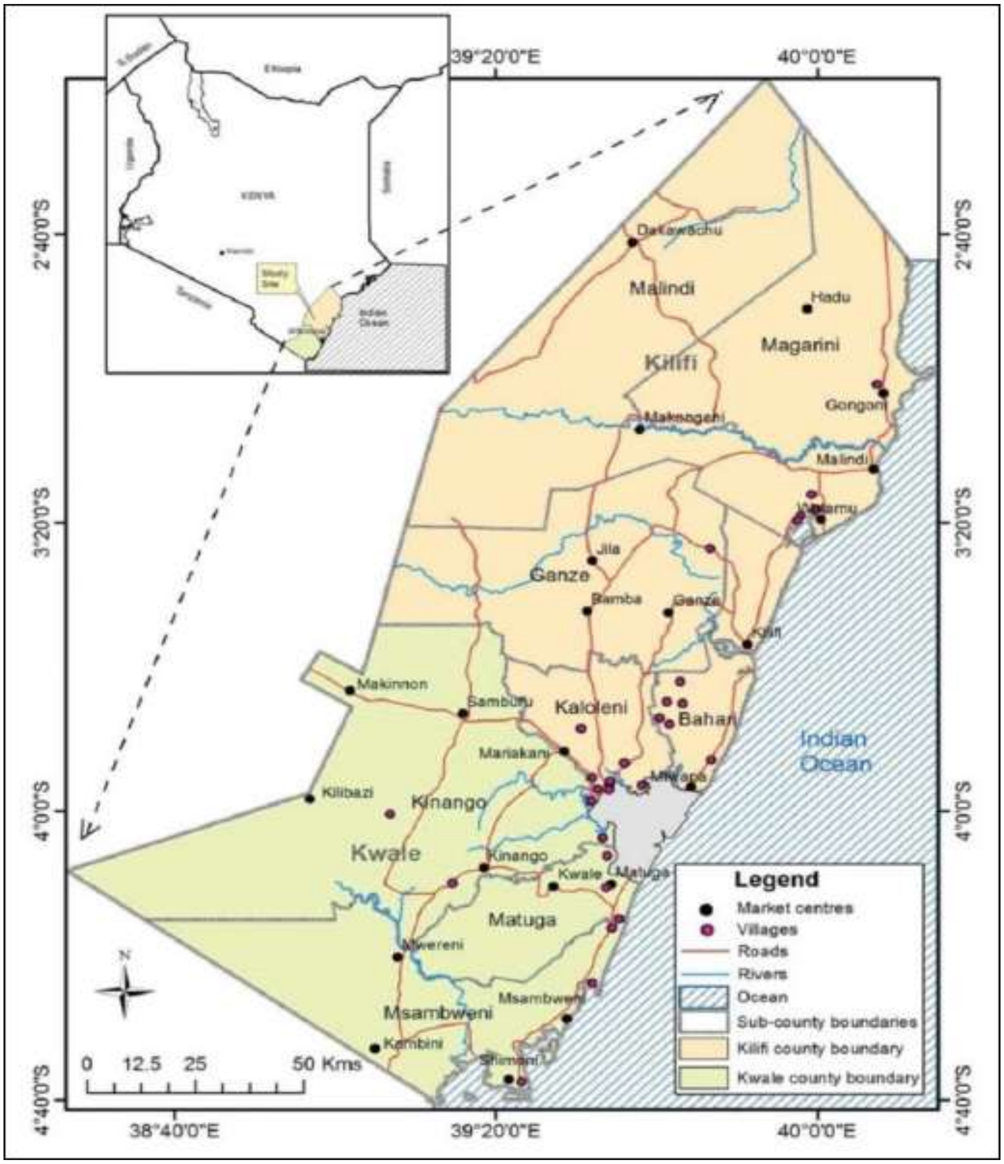

Figure 3.1: The map of coastal counties of Kilifi and Kwale

3.2 Samples Collection

Coconut varieties, East African Tall (Green), East African Tall (Yellow), East African Short (Green), and Dwarf Yellow were obtained from farmers at Malindi (Kilifi County) and Msambweni (Kwale County). In each variety, 50 coconut fruits were randomly (simple random) selected for subsequent analysis. All these coconut varieties were available in Kwale County, but not Kilifi County (i.e., only East African Tall -Green and

East African Short- Green were available). Maturity of the coconut varieties selected were known by the solid brown colouration of the husk. The coconut varieties, with their husks intact, were then stacked in sacks and transported in a well-ventilated van to Jomo-Kenyatta University of Agriculture and Technology post-harvest laboratory for subsequent analysis as shown in Figure 2.

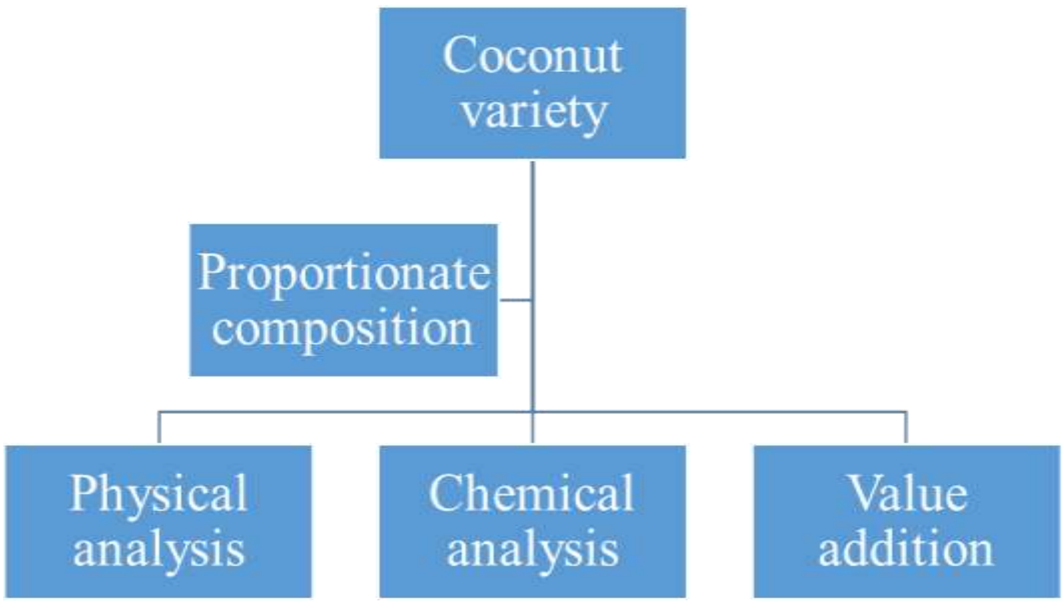

Figure 3.2: The study design

3.3 Determination of Coconut Fruit Composition (Proportionate Composition)

The various coconut fruits were first de-husked. The de-husked fruits were weighed using a weighing balance (ZZDP-201, Zhejiangyongkang, China), deshelled, and the various coconut components (shell, kernel, and water) separated. An illustration of the various components is shown in Figure 3. The individual components (i.e., shell, kernel, and water) were weighed and thereafter, the weight of individual component expressed as a percentage using the equation below.

% Proportionate composition = $\frac{W1}{W2}$ * 100

Where,

W_1 is the weight of the individual component (i.e., shell, kernel, or water)

W_2 is the weight of the de-husked coconut fruit

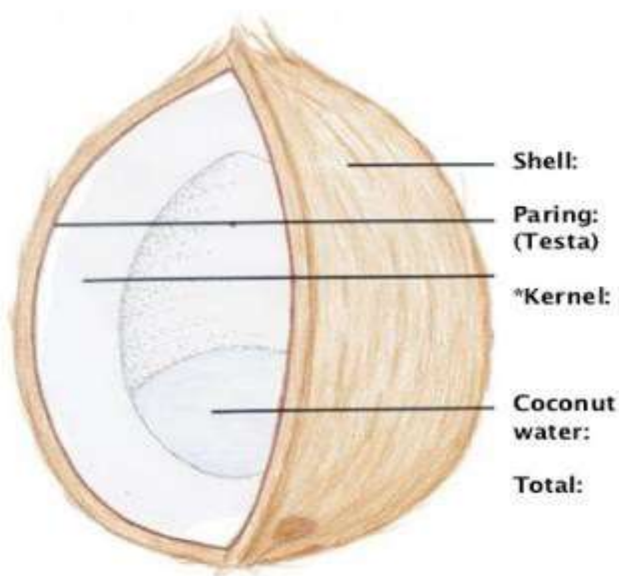

Figure 3.3: A visual illustration of the various parts of coconut fruit

3.4 Determination of Physical and Chemical properties of Coconut Kernel

3.4.1 Colour of the coconut kernel

The colour measurement for the coconut varieties was determined using hunter lab colour difference meter (Minolta, Chroma Meter CR-200; Minolta Camera Co., Ltd., Osaka, Japan). The instrument uses the principle of Opponent-Colour Theory assuming that the human eye receptors perceive colour as pairs of opposites: L*-scale (light vs. dark); a*-scale (red vs. green); and b*scale (yellow-blue) (Patil et al., 2017). Calibration of the instrument was done prior to colour measurement of samples with the aid of a white and black ceramic plate. The measurements were done in triplicate while putting into consideration the colour of three section readings (over 8mm aperture) of the sample. Values that were displayed on the colour meter screen were L* for lightness/darkness (100 for complete lightness and 0 for black), a* for chromaticity for red (+) to green (-), and b* for chromaticity from yellow (+) to blue (-). Total differences in colour (ΔE*) and the chromaticity difference (ΔC*) were also determined using the equations below:

$$\Delta E^* = \sqrt{[(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]}$$

$$C^* = \sqrt{[(\Delta a^*)^2 + (\Delta b^*)^2]}$$

$$\Delta C^* = C^*_{sample} - C^*_{standard}$$

Where,

ΔL*, Δa*, and Δb*are the differences between the corresponding colour element of the sample and the standard (L* = 93.55, a* = 0.84, and b* = 0.37).

3.4.2 Proximate analysis

Prior to the determination of the proximate analysis, the various coconut sample varieties were first de-husked followed by de-shelling, and then grating of the meat or kernel. The proximate analyses of the coconut meat, done in triplicates, were carried out according to AOAC (2000) methodology as follows: ash by gravimetric method, crude protein by semi micro-Kjedahl method, crude fat by Soxhlet method, crude fibre by acid and alkali digestion, and carbohydrates by difference.

3.4.1.1 Moisture content

About 5g of the sample was weighed and also the weight of the moisture dish taken. The sample(s) while in the moisture dish was placed in the moisture oven and the temperature upscaled to 105°C (AOAC, 2000). The sample(s) was then dried at this temperature until constant weight was achieved, removed, cooled in a desiccator, and ultimately weighed. The amount of moisture in the sample(s) was calculated using the formula below:

$$\% \text{ Moisture} = \frac{W1-W2}{W3} * 100$$

Where,

W1= weight before drying; *W2*= weight after drying; *W3*= sample weight

3.4.1.2 Ash

About 5g of the sample(s) was weighed into a clean crucible (weight also taken), and then charred in a fume hood by heating until smoking stopped (AOAC, 2000). The charred sample(s) was transferred into a muffle furnace and temperature adjusted to 550°C. The sample (s) was then ashed until all the organic matter was pyrolyzed (i.e., fully combusted into ash). The sample(s) was removed using a tongue and placed in desiccator to cool, and finally weighed in calculating the amount of ash aided by the following formula:

$$\% \text{ Ash} = \frac{W1-W2}{W3} * 100$$

Where,

W1 = weight of crucible with ash; *W2* = weight of empty crucible; *W3* = sample weight

3.4.1.3 Crude fibre

About 2g of the sample(s) was weighed and placed into 200 ml of 1.25% sulphuric acid and boiled for 1 hour (AOAC, 2000). Then, the solution and content were poured into Buchner funnel equipped with glass wool, allowed to cool, and filtered. Consequently, the residue was boiled in 200ml of sodium hydroxide for 1 hour, transferred again onto the Buchner funnel for filtering. The resulting residue was washed with alcohol and petroleum ether subsequently. The final residue was placed onto a clean crucible (weight already taken), dried in the moisture oven for 1 hour (at constant weight), removed, cooled in a desiccator, and weighed. The crucible(s) containing the sample(s) was placed in a muffle furnace for 1 hour, removed, cooled, and weighed. The difference in weight (loss in ignition) was recorded as crucible fibre and expressed in crude fibre as shown in the formula:

$$\% \text{ Crude fibre} = \frac{W1-W2}{W3} * 100$$

Where,

W_1 = weight of sample before incineration; W_2 = weight of sample after incineration; W_3 = weight of original sample.

3.4.1.4 Crude protein

About 2g of the sample(s) was weighed into a digestion flask and a combined catalyst comprising of 5g of potassium sulphate and 0.5g of copper sulphate added as well as 15 ml of sulphuric acid (AOAC, 2000). The mixture was then heated in a fume hood until the digest colour became blue, signifying the end of the digestion process. After cooling the digest, it was transferred into 100 ml volumetric flask and topped up to the mark with deionised water. Meanwhile a blank digestion was also prepared. 10 ml of the diluted digest was then transferred into the distilling flask and washed with distilled water. This was followed by addition of 15 ml of 40% sodium hydroxide, and also washed with distilled water. Distillation was done to a volume of 60 ml distillate, and finally the distillate was titrated using 0.02N hydrochloric acid (HCL) to orange colour (end point signification) of the mixed indicator.

The percentage nitrogen was calculated as follows:

$$\%N = (V1- V2) * N * F * 100/ (V * 100/S)$$

Where,

V1 is the titre for sample in ml, V2 is titre for blank in mL; N= normality of standard HCL; f= factor of standard HCL solution; V= volume of diluted digest taken for distillation; S= weight of sample taken for distillation.

The percentage protein was then determined as follows:
% protein= nitrogen * protein factor (6.25)
3.4.1.5 Crude fat

About 5 g of the sample was weighed into an extraction thimble and stoppered with defatted cotton wool, and placed in the extraction apparatus (AOAC, 2000). A clean flask was weighed and filled with petroleum ether up to two-thirds. The Soxhlet apparatus was set by fixing the extraction apparatus on the flask and connecting them to a condenser to start fat extraction for about over eight hours. The extraction solvent was then rota-evaporated and the extracted fat dried in hot air oven at 70C for 15 minutes and final weight of the flask taken. The percentage crude fat content was then determined as follows:

$$\% \text{ Crude fat} = \frac{W1-W2}{W3} * 100$$

Where,

W_1 = weight of the flask with extracted oil; W_2 = weight of the empty flask; W_3 = weight of original sample.

3.4.1.6 Carbohydrate

Carbohydrate was determined by difference [i.e., 100 – (crude fat +crude protein +ash + moisture + crude fibre)].

3.4.3 Fatty acid profile

$NaOCH_3$-MeOH methylation was used in extracating fatty acid methyl esters (Wang et al., 2015). In this process, 0.5g of dry ground coconut kernel was measured and placed in the test tube and 2ml of 0.5M sodium methoxide solution added. The tubes were then reacted for 1hour 50 minutes at 55^0C in the oven with mixing for 5 seconds after every 20minutes. Then, 2 ml of saturated soidum bicarbonate and 3 ml of n-hexane were added followed by well-mixing of the tubes. Finally, the extracts (organic layer containing the fatty caid methyl esters) were removed and used for gas chromatography (GC) analysis. Agilent 7890B gas chromatograph (Agilent Technologies, Stevens Creek Blvd, Santa Clara, CA, United States) equipped with DB-FATWAX UI, 30 m x 0.25 mm, 0.25 μm column attached to mass spectrometry (MS) detector. Conditions set for analysis included: split mode of injection (split ratio 50:1) at 250°C; oven temperature 50°C (2min), 50°C/min to 174°C (14 min), 2°C/min to 215 °C (25 min); hydrogen as the carrier gas at constant flow, 40 cm/s @ 50°C, and injection volume (1 µL). Fatty acid identification was done using the standard FAME mix. The composition of fatty acid was reported by the normalisation method and expression done in terms of percentage relative compostion of individual fatty acids.

3.5 Coconut Ice Cream

3.5.1 Production of coconut ice cream

The recipe for coconut ice cream was obtained from Fellows (2008), and some modifications done. To start with, 4 litres of coconut milk were made from 13 coconut fruits' kernel. The coconut milk was obtained by griding the coconut kernel in the presnece of water , and then sieving with a muslim cloth. The milk was then heated to 45°C and dry ingredients (skim milk powder, refined sugar, and stabiliser) added and mixed. Sieving was done and whipping cream added. The ice cream mix was heated to 65°C and blended for five minutes. Further heating was done to 72°C and held for 2 minutes. The mix was cooled to room temperature and left to age in the cold room overnight. Finally, freezing of the mix was done in the ice-cream machine, and the resulting ice cream packaged and hardened in the deep freezer. For vanilla-flavoured coconut ice cream, vanilla was added before freezing the mix. The same process was used in making ice cream from the cow's milk to be used as a control.

3.5.2 Sensory evaluation of coconut ice cream

The following day, the sensory evaluation was done by 30 untrained panellists consisting of both undergraduate and graduate students from the Department of Food Science, Jomo-Kenyatta University of Agriculture and Technology. A 9-point hedonic scale questionnaire with 1 representing extreme dislike and 9, extreme like, was used as the basis for evaluating texture, appearance, taste, flavour, and overall acceptability

3.6 Statistical Analysis

The results from the survey were analysed using excel (Microsoft, Redmond, Washington, United States). In addition, the results from physical and chemical analysis of coconut kernel were subjected to analysis of variance (ANOVA) using Stata software version 13 (Stata Corp, College Station, TX, USA), and expressed as means ± standard deviations and separation of means carried out by the Bonferroni adjustment at $p<0.05$.

CHAPTER FOUR

RESULTS AND ANALYSIS

4.1 Field Survey

From the field survey at the coastal counties of Kwale and Kilifi, the coconut varieties evident were East African Tall (Green), East African Tall (Yellow), East African Short (Green), and Dwarf -Yellow. All these varieties were available in Kwale County, while in Kilifi County, only two varieties were available: East African Tall (Green) and East African Short (Green). Maturity of the coconut varieties, before harvesting, was known by the solid brown colouration of the husk. Coconut fruit with the husk would stay for more than one month after harvest, but after de-husking the coconut would be stored for less than week due to possible cracking of the shell. The processors had no preference to specific variety, which may be attributed to lack of research in ascertaining the kernel yields from each variety

From the six visited processors (Coco Vita Limited, Kentaste, Amor Cocco, Ramisi Coconut Processors, Kilifi Social Enterprise, and Mama Sonje), the products made, based on frequency, are presented in the Figure 3 below. Evidently, virgin coconut oil (VCO) was prevalent in almost all the visited processors (31%), followed by desiccated coconut (23%), then copra oil (16%), coconut milk (7%), coconut cream (7%), coconut flour (7%), and coconut syrup (7%). VCO, copra oil, and coconut syrup had a shelf-life of one year. On the other end, coconut cream, coconut milk, desiccated coconut, and coconut flour had a shelf-life not exceeding six months. These products are limited as compared to those produced in major coconut growing areas such as India, Philippines and Sri Lanka: such countries produce additional products such as coconut ice cream, coconut yoghurt, coconut butter, coconut jam, coconut candy, which are lacking in Kenya (AFA-NOCD, 2015). Before processing of these coconut-kernel based products especially, coconut milk, coconut cream, desiccated coconut, and VCO, quality of the kernel was ascertained by removing the testa as much as possible. This ensured that the final product was milky-white for consumer acceptability.

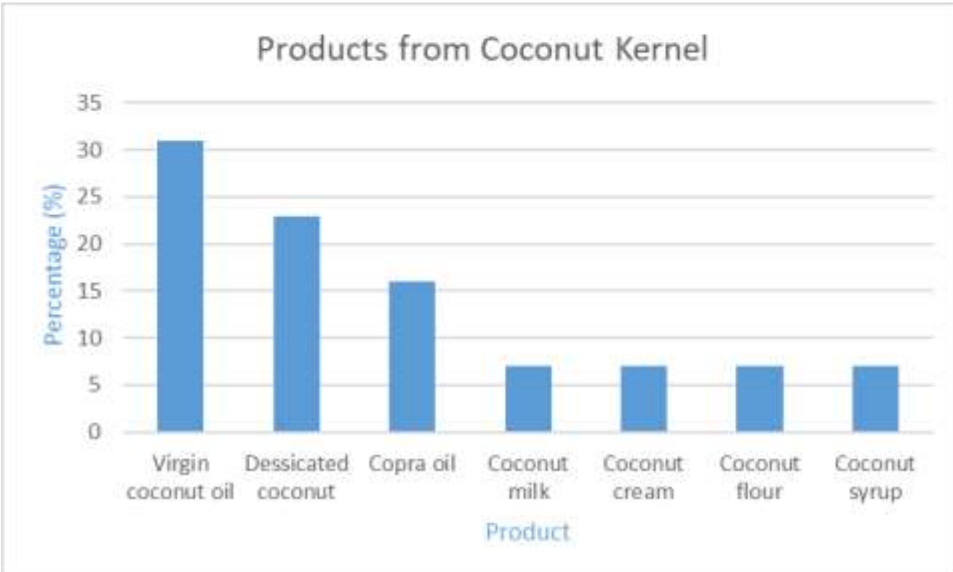

Figure 4.1: Food-based products from coconut kernel

Obviously, the underutilisation of the coconut sub-sector as evident by limited number of food-based products generated from coconut kernel mentioned above, are attributed to various challenges listed in Figure 4 below. Notably, limited coconut supply to the processors was a major challenge (25%) being attributed to pest and diseases, and mass purchase by Tanzanian traders. This was followed by limited value-added products from coconut (i.e., coconut kernel) and traditional processing characterised by obsolete technology and machines used in making the coconut-kernel-based products each represented by 17%. Insufficient capital for business expansion especially among the small enterprises was represented by 14%. Other challenges included limited marketing and, therefore, customer are not aware of the products (8%), lack of labelling (i.e., products not labelled at all despite being packaged) (6%) faced by mainly by small enterprises, immature nuts been brought for processing (6%), insufficient research in the coconut sub-sector (6%), and cracking of nuts during storge prior to processing (3%).

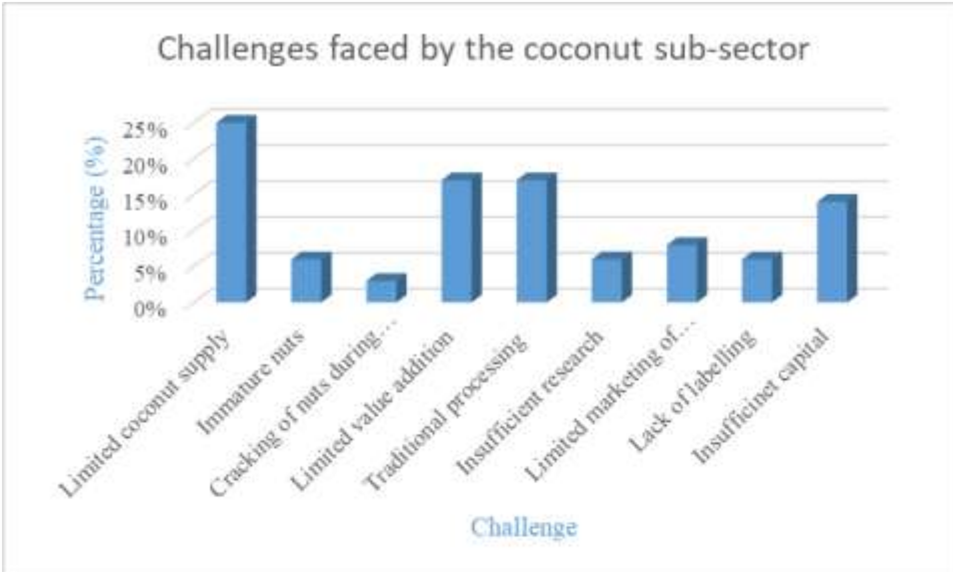

Figure 4.2: Challenges faced by coconut sub-sector

4.2 Coconut Fruit Composition

Among the three de-husked coconut fruit constituents, coconut kernel had the highest composition (45.10±1.64% - 50.32±0.16%), followed by coconut shell (25.93±0.72% - 28.46±0.29%), and lastly water (23.75±1.07% - 27.11±1.49%) with no significant difference among the varieties except the coconut kernel of varieties from Kilifi County (Table 4). A similar order in the composition of kernel, shell, and water is supported by the existing literature on coconut fruit composition (DebMandal and Mandal, 2011 and Wynn, 2017). Accordingly, the East African Tall – Green (EAT-G) from Kilifi County had the highest kernel (50.32±0.16%) as compared to its counterpart from Kwale county making it ideal for processing of coconut-food products. In terms of kernel weight, it ranged between 0.20±0.01kg - 0.27±0.01kg (Figure 5), which, however, is low as compared to kernel weight of coconut grown in major producing countries such as Indonesia, ranging between 0.32kg and 0.6kg (Tuhumuri et al., 2016). Such a difference is associated with differences in coconut variety, stage of maturity, geographical location, and cultural practices (Seriphan and Benjakul, 2015 and Patil et al., 2017). The kernel weight, which is related to its overall composition, is a critical parameter in terms of production with higher weight leading to higher production efficiency due to generation of more kernel-based products as compared to lower weight (Mpagalile, 2005 and Sangamithra, 2013).

Table 4.1: Percentage composition (weight) of coconut kernel, water, and shell

County	Variety	Kernel (%)	Water (%)	Shell (%)
Kwale	EAT-G	47.08±1.80[a]	25.34±0.92[a]	27.58±0.72[a]
	EAS-G	45.10±1.64[a]	27.11±1.49[a]	28.46±0.29[a]
	EAT-Y	47.26±0.40[a]	24.48±0.47[a]	28.27±0.38[a]
	D-Y	48.05±0.15[a]	25.58±0.51[a]	26.37±0.57[a]
	p-value	0.13	0.17	0.07
	EAS-G	48.07±0.27[b]	24.50±0.53[a]	27.10±0.54[a]
	p-value	0.001	0.10	0.09

EAT-G: East African Tall Green; *EAS-G*: East African Short Green; *EAT – Y*: East African Tall Yellow; and *D – Y*: Dwarf Yellow. Values are means ± standard deviation (n=18). Means with different superscript letters in the same row are significantly different at $p<0.05$

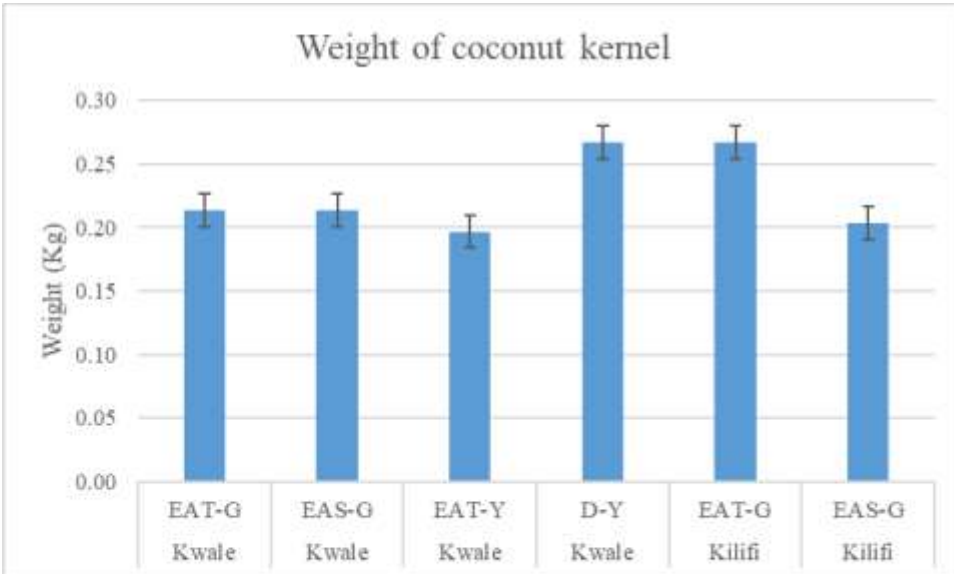

Figure 4.3: Weight of the coconut kernel

4.2 Colour of Coconut Kernel

Generally, L* values (i.e., signifying lightness) were high (85.23±0.76 - 93.35±0.30) as evident in Table 5. Coconut kernel has a milky white colouration, and indication of lightness as manifested by high L* values (Patil et al., 2017). Low b* values (blueness) (1.50±0.03 - 2.20±0.05), and lastly a* values (redness) (0.50±0.14 - 0.81±0.02) as show in Table 5, was expected sine the coconut kernel is white. These values (i.e., high L* values and low a* and b* values) agree with those generated by other studies on colour determination of coconut kernel (Ghosh et al., 2014 and Patil et al., 2017). Notably, only the L* values were different among the coconut varieties especially from Kwale county. Accordingly, the highest L* value was observed in Dwarf Yellow (93.35±0.30), while the lowest in East African Tall- Green (85.34±0.15). Also, ΔE* (the change in colour with reference to standard) was different across the coconut varieties from Kwale county: the highest ΔE* was observable in EAT-G (7.80±0.12), whereas the lowest in D-Y (1.51±0.11). Such differences can be attributed to genotypic variation (Patil et al., 2017).

Table 4.2: Colour of coconut kernel

County	Variety	L*	a*	b*	ΔE*	ΔC*
Kwale	EAT-G	85.34±0.15^{a}	0.56±0.07^{a}	1.78±0.29^{a}	7.80±0.12^{a}	1.44±0.27^{a}
	EAS-G	86.15±0.15^{a}	0.67±0.18^{a}	1.53±0.04^{a}	6.95±0.14^{a}	1.18±0.03^{a}
	EAT-Y	92.08±1.87b	0.81±0.02a	2.20±0.05a	2.43±0.97b	1.83±0.05a
	D-Y	93.35±0.30b	0.51±0.01a	1.79±0.03a	1.51±0.11c	1.46±0.03a
	p-value	<0.001	0.08	0.13	<0.001	0.1
	EAT-G	85.23±0.76^{a}	0.50±0.05^{a}	1.52±0.05^{a}	7.86±0.05^{a}	0.50±0.05^{a}
Kilifi	EAS-G	86.22±0.54a	0.50±0.02a	1.50±0.03a	6.89±0.86a	1.18±0.16a
	p-value	0.09	0.1	0.3	0.08	0.12

EAT-G: East African Tall Green; *EAS-G*: East African Short Green; *EAT – Y*: East African Tall Yellow; and *D – Y*: Dwarf Yellow. Values are means ± standard deviation (n=54). Means with different superscript letters in the same row are significantly different at $p<0.05$

4.3 Proximate Analysis

As evident in Table 6, the proximate analysis revealed high moisture content (43.17±0.70 - 48.23±0.79%), followed by crude fat (35.01±1.0 - 38.28±1.09%), then carbohydrate (6.15±0.25-13.30±0.37%), crude protein (3.63±0.28 - 5.81±0.21%), crude fibre (2.14±0.25 - 3.75±0.09%), and lastly ash content (1.02±0.40 - 1.30±0.34%). A similar order (i.e., moisture content being the highest and ash content the lowest) is supported by existing studies (Dendy and Timmins, 1973; Grimwood & Ashman, 1975; Balachandran et al., 1985; Chakrabotty, 1985; Kwon et al., 1996; Patil et al., 2017 and Wynn, 2017).

Crude fat content did not vary significantly among the varieties in both counties. East African Tall- Yellow (EAT-Y) had the highest crude fat content (38.28±1.09%), while East African Short-Green (EAS-G) had the lowest crude fat content (35.01±1.0), all of which came from Kwale county. These values compared well with the range reported by Appaiah et al. (2014) and Patil et al. (2017). Crude fat content of coconut is directly proportional to the extractable oil content (Sangamithra et al., 2013 and Ghosh et al., 2014), and therefore EAT-Y from Kwale county would be preferable for the production of oil-based coconut products.

For carbohydrate, the results indicated a significant difference across the varieties especially from Kwale County. EAS-G had the highest content (13.30±0.37%) and EAT-Y the least content (6.15±0.25%), all from the same county (i.e., Kwale). This variation may be attributed to genotypic difference between the varieties. Nonetheless, comparison based on the two counties show variation in carbohydrate content, for example, EAS-G from Kwale recorded carbohydrate content of 13.30±0.37%, whereas EAS-G from Kilifi had carbohydrate content of 10.39±0.20%, and such variation may be due to difference in coconut variety, stage of maturity, and geographical location (Seriphan and Benjakul, 2015).

Crude protein did not vary significantly across the coconut varieties in both counties. D-Y had the highest crude protein content (5.81±0.21%), while EAS-G had the lowest content (3.63±0.28%) with the variation being attributed to genotypic difference (Chakrabotty, 1985; Kwon et al., 1996 and Pham, 2016).

Crude fibre, just like crude protein, did not differ significantly across the varieties in each County. The highest crude fibre content was recorded by D-Y (3.75±0.09%) whereas the least crude fibre content was observed in EAS-G (2.14±0.25%) with genotypical variation being the likely cause. A similar range is supported by other studies on the fibre content of coconut kernel (Kwon et al., 1996; Pham, 2016). The fibre content is important in diet decreasing chances of constipation and maintaining bowel health (Barber et al., 2020).

Similarly, the total ash did not vary significantly among the varieties in both counties. D- Y had a relatively high ash content (1.30±0.34%) compared to EAS-G, which had the lowest ash content (1.02±0.40%) with the possible cause of this variation being varietal difference and soil composition. This range is an agreement with the findings of most studies on ash content of coconut kernel (Chakrabotty, 1985; Kwon et al., 1996; Patil et al., 2017 and Wynn, 2017).

Finally, moisture content differed significantly across varieties grown in Kwale county as opposed to Kilifi County. The highest moisture content was observed in EAT-G (48.23±0.79%) while the lowest moisture content was realised by D-Y (43.17±0.70%). Low moisture, unlike high moisture, is preferable since water content in indirectly proportional to the dry matter required for the crispiness of coconut flakes, durability of coconut flour, and increased production of virgin coconut oil and coconut protein powder (Sangamithra et al., 2013) and as such, D-Y would be preferable.

Table 4.3: Proximate composition of coconut kernel

Count	Variet	%Moisture	%Ash	%Fat	%Protein	%Fibre	%Carbohydra
Kwal	EAT-	48.23±0.7	1.14±0.3	37.28±1.0	3.95±0.2	2.53±0.7	7.41±0.56^{a}
	EAS-	45.31±0.4	1.02±0.4	35.01±1.0	3.63±0.2	2.14±0.2	13.30±0.37a
	EAT-	47.28±0.4	1.15±0.8	38.28±1.0	4.57±0.1	3.26±0.6	6.15±0.25ab
	D-Y	43.17±0.7	1.30±0.3	36.14±0.3	5.81±0.2	3.75±0.0	10.20±0.12c
	p-	<0.001	0.17	0.21	0.07	0.15	<0.001
	EAT-	46.00±0.3	1.15±0.4	36.43±0.9	4.49±0.3	2.92±0.4	9.27±0.48^{a}
Kilifi	EAS-	46.77±0.1	1.08±0.3	35.65±0.8	3.79±0.4	2.34±0.5	10.39±0.20^{a}
	p-	0.97	0.76	0.16	0.85	0.61	0.12

EAT-G: East African Tall Green; *EAS-G*: East African Short Green; *EAT – Y*: East African Tall Yellow; and *D – Y*: Dwarf Yellow. Values are means ± standard deviation (n=54). Means with different superscript letters in the same row are significantly different at p<0.05

4.4 Fatty Acid Profile

Table 7 shows the fatty acid profiles of coconut kernel, and revealed that the highest component was lauric- C12:0 (45.91±0.32% - 50.72±0.73%) and the least was arachidic - C20:0 (0.17±0.03% – 0.19±0.23%). These values are supported by other studies (Laureles et al., 2002; Azeez, 2007; Ghosh et al., 2014; Pham, 2016 and Boateng et al., 2016). A significant difference was only observed in the values of lauric and myristic across the varieties from Kwale county. From the results, over 90% of the coconut oil was saturated (caproic - C6:0, caprylic - C8:0, capric - C10:0, lauric - C12:0, myristic- C14:0, palmitic- C16:0, stearic- C18:0, and arachidic - C20:0). Additionally, the ratio of saturated fatty acid (SFA - C6:0, C8:0, C10:0, C12:0, C14:0, C16:0, C18:0, and C20:0): monounsaturated fatty acid (MUFA – C18:1): polyunsaturated fatty acid (PUFA – C18:2) was found to be 1: 0.06: 0.02 confirming the 91% saturation, which does not meet the recommendation by the American Heart Organisation of 1:1:1 (SFA: MUFA: PUFA) in edible fats and oils (Gulla and Waghray, 2011).

Among the coconut varieties, EAT-G from Kwale county seemed to relatively have high level of saturation with a lauric content of 50.72±0.73% in comparison to D-Y, which had the lowest lauric content (45.91±0.32%), from the same county and, therefore, the variation is attributable to genotypic difference. This high level of saturation was attributed to high atherogenicity index (18.03±0.71 – 19.57±0.68) and thrombogenicity index (8.48±0.56 – 9.32±0.87) of the oil extracted from the kernels of various coconut verities. Atherogenicity index (AI) and thrombogenicity index was calculated by dividing the amount of caproic acid (C6:0) with that of oleic acid (monounsaturated fatty acid), and dividing the amount of C6:0 and C8:0 (caprylic acid) with that of oleic acid, respectively (Munhoz, 2018). High atherogenicity and thrombogenicity indices are indicators of susceptibility of the consumers to developing cardiovascular diseases. Accordingly, Boateng et al. (2016) argue that since coconut oil is saturated, it is not highly preferred by a section of health-conscious consumers. Nonetheless, the presence of high-level saturated acids is an indication of shelf stability of the coconut oil (Ghosh et al, 2014).

Also, it should be noted that palmitic acid which is the most abundant and highly lipotoxic dietary fatty acid (Martinez et al, 2015 and Carta, 2017), is relatively low in coconut oil (Table 7). Moreover, almost half coconut oil comprises of lauric acid (commercially, coconut oil is referred to as lauric acid), a medium chain fatty acid which upon absorption is transported directly to the liver (unlike the long chain fatty acids), where it is metabolized to produce energy and ketone bodies, rather than being stored as fat (Dayrit, 2015). Apart from the medium chain fatty acids, coconut contains the beneficial monoglyceride, monolaurin, which is antimicrobial (antibacterial, antiviral, and antifungal), antitoxic, immune-modulating, and metabolic-enhancing, (Azeez, 2007; Ghosh et al., 2014 and Pham, 2016). The main limitation of coconut oil usage as a dietary fat, however, is its low level of essential fatty acid, linoleic acid (Azeez, 2007).

Table 4.4: Fatty acid analysis of coconut kernel in percentage (%)

Count	Variet	Caproic	Caprylic	Capric	Lauric	Myristic	Palmitic	Stearic	Oleic	Linoleic	Arachidi
Kwal	EAT-	0.72±0.21	6.99^{a}±0.6	4.87±0.6	50.72±0.7	16.53±0.4	11.18±0.8	2.64±0.6	4.57±0.4	1.94±0.1	0.17±0.0
	EAS-	0.90±0.21	7.43±0.3	5.87±0.7	47.13±0.9	18.06±1.0	9.22±0.83	3.20±0.5	6.08±0.6	2.17±0.4	0.19±0.2
	EAT-	0.64±0.23	8.35±0.2	7.22±0.1	47.47±0.4	17.02±0.1	8.71±0.41	3.09±0.0	5.14±0.2	2.19±0.2	0.18±0.0
	D-Y	0.73±0.30	8.65±0.2	5.46±0.3	45.91±0.3	20.47±0.4	8.53±0.43	2.84±0.1	5.31±0.3	2.20±0.2	0.18±0.0
	p-value	0.12	0.11	0.21	0.001	<0.001	0.1	0.06	0.31	0.13	0.81
Kilifi											
	EAS-	0.77±0.24	7.44±0.3	5.41±1.1	48.73±2.5	17.76±1.3	9.48±1.06	2.89±0.5	5.68±0.9	2.00±0.0	0.17±0.0
	p-	0.98	0.30	0.22	0.25	0.95	0.53	0.70	0.08	0.15	0.41

EAT-G: East African Tall Green; *EAS-G*: East African Short Green; *EAT – Y*: East African Tall Yellow; and *D – Y*: Dwarf Yellow. Values are means ± standard deviation (n=54). Means with different superscript letters in the same row are significantly different at $p<0.05$

4.5 Sensory Evaluation of Coconut Ice Cream

Sensory evaluation of the developed product from coconut kernel i.e., coconut ice cream (pure and vanilla-flavoured), and cow milk (control) is presented in Table 8. There was no significant difference in the attributes such as texture and overall acceptability. However, there were differences in appearance, taste, and flavour. In terms of appearance, vanilla flavoured coconut and cow milk's ice cream scored higher (7.52±1.14 and 7.68±0.25 respectively) as compared to the pure coconut (6.02±0.98). Regarding taste and flavour, the pure coconut was preferred in comparison to the vanilla-flavoured coconut and cow milk's ice cream. Generally, pure coconut ice cream was preferred due to the inherent nutty flavour, and health benefits attributed to its nutritional content (Jayasundera & Fernando, 2014).

Table 4.5: Sensory evaluation of coconut ice cream

Sample	Appearance	Taste	Flavour	Texture	Overall Acceptability
Pure Coconut	$6.02^{a}\pm0.98$	$8.00^{a}\pm1.16$	$7.97^{a}\pm1.35$	$7.97^{a}\pm2.14$	$7.90^{a}\pm1.12$
Coconut (vanilla)	$7.52^{b}\pm1.14$	$7.99^{a}\pm0.46$	$6.98^{ac}\pm1.32$	$7.90^{a}\pm0.59$	$7.86^{a}\pm0.87$
Cow Milk	$7.68^{a}\pm0.25$	$6.75^{a}\pm0.18$	$5.92^{a}\pm0.25$	$7.62^{a}\pm0.74$	$7.22^{a}\pm0.38$
p-value	0.02	0.04	<0.001	0.36	0.53

Values are means ± standard deviation (n=30). Means with different superscript letters in the same row are significantly different at p<0.05

CHAPTER FIVE

SUMMARY, CONCLUSION AND RECCOMENDATIONS

5.1 Summary

The present study was aimed at exploring coconut utilization through value addition of coconut kernel to produce coconut ice cream at the coastal counties of Kilifi and Kwale. A structured interview with lead questions was used in knowing the coconut varieties grown at the coastal part of Kenya, food-based products made from the coconut kernel, and the challenges facing enterprises in the coconut value chain. This was followed by random sampling of coconut fruits, which were then de-husked and de-shelled in determining coconut fruit composition. Subsequently, colour analysis of the coconut kernel was done using hunter lab colour difference meter. Additionally, proximate analysis and fatty acid profile of coconut kernel was caried out as guided by AOAC (2000) methods and base-catalysed transesterification respectively. Finally, coconut milk was extracted to make coconut ice cream followed by sensory evaluation.

The field survey revealed that four varieties of coconut were evident: East African Tall (Green) -, East African Tall (Yellow), Dwarf (Yellow), and East African Short. limited coconut-kernel based products was evidenced by only six products (virgin coconut oil, desiccated coconut, copra oil, coconut milk, coconut cream, and coconut flour). This was attributed to challenges such as obsolete technology and machines, insufficient capital for business expansion, limited marketing, immature nuts being used, cracking of nuts during storage, and insufficient research. based on the de-husked coconut fruit, coconut kernel was the highest in comparison to shell and water across the coconut varieties. Regarding colour, generally high L* (light vs. dark) values (85.34 - 93.35±1.64) and low a* (red vs. green) values (0.51-0.81) and b* (yellow versus blue) values (1.53-2.20) values, justifying the milky-white colouration of the kernel. Notably, proximate analysis revealed high crude fat (35.01-38.28%) across the varieties. Fatty acid profile revealed that the highest fatty acid in composition was lauric (45.91-

50.72%). Between the developed ice cream, pure coconut flavour was the most preferred.

5.2 Conclusion

The field survey of the coconut value chain at the coastal counties of Kwale and Kilifi Kenyan found that four varieties are coconut are available, and they included East African Tall (Green), East African Tall (Yellow), East African Short (Green), and Dwarf Yellow. Additionally, limited products of coconut kernel were evident such as VCO, desiccated coconut, copra oil, coconut milk, coconut cream, and coconut flour. Accordingly, these few products were attributed to challenges facing the coconut sub-sector in Kenya such as limited value-added products, obsolete technology and machines used in making the coconut-kernel-based products, insufficient capital for business expansion, limited marketing, lack of labelling, immature nuts, cracking of nuts, and insufficient research.

Regarding the physical and chemical properties of coconut kernel from different coconut varieties, to begin with, it was found that coconut meat/kernel was the highest in proportion as compared to coconut water and shell. Subsequently, colour analysis revealed L* values signifying lightness (milky-white colouration) of the coconut meat, and low a* and b* values. Additionally, proximate analysis showcased high moisture content as expected in the case of a high moisture food-content like coconut, followed by crude fat, then carbohydrate, crude protein, crude fibre, and ash. Fatty acid analysis revealed high lauric acid content with most of the oil extract being saturated (91%). This was an indication of stability for storage and suitability for use on ketogenic diets.

In terms of development and sensorily evaluation of coconut ice cream versus a positive control (an ice cream made from the cow milk), the two flavours made, the pure coconut flavour was the most preferred and scored relatively high among the panellists. This was attributed to the inherent nutty flavour and health benefits attributed to coconut's nutritional content.

Overall, production of coconut ice cream proved to be effective in broadening coconut value chain addition. In addition, the physical and chemical properties of coconut kernel indicated which coconut variety may be useful and efficient in coconut value chain addition.

5.3 Recommendations

i. The coconut ice cream developed was not evaluated in terms of physical and chemical properties, and stability. Therefore, in addressing this limitation of the study, it is recommended that the properties of the coconut ice cream and stability be considered in a future study.

ii. The study was also limited by not determining the physical and chemical properties of two coconut varieties (East African Tall -Yellow, and Dwarf Yellow) in Kilifi County. To this end, it is highly recommended that in the future, a study be carried out in ascertaining the physio-chemical properties across these two varieties in Kilifi County.

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APPENDICES

Appendix I: Interview Questions

Broadening Utilization of Coconut Kernel through Production of Coconut Ice Cream

Section 1: Processor/Farmer's Details

Name: ……………………………………………………………….

Farmer/self-help group/processor: …………………………………….

Coastal region/County: ………………………………………………….

Section 2: Interview questions for the farmer(s)

S/N	Question	Comments
1.	At what stage is the coconut harvested for kernel processing?	
2	Which varieties of coconut do you grow?	
3.	Is there difference in coconut yields based on the varieties?	
4.	After harvesting, how long can the coconut fruit stay before processing?	
5.	Do you process coconut into other products at the farm level?	
6.	Which challenges do you face as a coconut farmer?	

Section 3: Interview questions for the coconut processors

S/N	Question	Comments
1.	At what stage is the coconut mature to be harvested for processing?	
2	Do you have a preference for the coconut variety to be used for processing?	

4.	After harvesting, how long can the coconut fruit stay before processing?	
5.	Which quality parameters are checked if any before the kernel is processed?	
6.	Which products are made from coconut kernel (edible coconut oil, milk, cream, desiccated coconut, e.t.c)?	
7.	What is the acceptability of the product derived from the nut kernel among customers/consumers? Has customers raised any issue in regard to the product quality?	
8.	What is the shelf-life of the product generated from coconut kernel?	
9.	Which challenges are faced during the coconut kernel processing?	