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CAUSES AND CONTROL OF POSTHARVEST FRUIT ROT OF SOME NEGLECTED FRUIT TREES IN THE GREATER ACCRA AND EASTERN REGIONS OF GHANA

BY

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THIS THESIS IS SUBMITTED TO THE CROP SCIENCE DEPARTMENT, UNIVERSITY OF GHANA, LEGON IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF MPHIL CROP SCIENCE (POST-HARVEST TECHNOLOGY) DEGREE

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DECLARATION

1, OPPONG GEORGIETTE, hereby declare that with the exception of works cited which are duly acknowledged, the work reported herein is the result of my original research findings and has not previously been submitted by me or anyone for a degree at any other university or institution of higher education.

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DEDICATION

This work is dedicated to the Glory of God, my father Nana Agyei Donsah, Dr. Clement Oppong and my family for their selfless contribution towards my education, their love and relentless support throughout the years.

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ABSTRACT

There are a wide range of fruits found in Ghana, both indigenous and introduced. Some of these fruits have been neglected over time and therefore suffer high postharvest losses due mainly to rots caused by fungal pathogens. A study was therefore undertaken to: assess the knowledge, perception and experience of farmers and retailers of soursop, sweetsop and African star apple on harvest and postharvest losses and their causal factors; describe the symptoms of postharvest rot diseases associated with the fruits and identify the microorganisms causing the rot diseases; determine the frequency of occurrence of the fungal pathogens associated with the diseased fruits and evaluate the efficacy of neem seed extract, pawpaw seed extract, soursop seed extract and Zamir 40 EW (prochloraz + tebuconazole) for control of postharvest rots in the fruits. A questionnaire survey was carried out at the farmer level in the Eastern region and retailer level (selected markets and grocery shops) in the Greater Accra region to obtain information on postharvest losses incurred in the harvest and handling of the fruits. Using snowball sampling, 90 farmers were interviewed while 90 retailers were selected at random (30 within each of three authoritatively sampled markets) and grocery shops. Data from the survey were analyzed using IBM Statistical Package for Social Sciences (SPSS) software version 24. Description of disease symptoms on fruits were done by visual observation of colour and feeling of diseased tissue with fingers for texture, while noting signs of the fungus/fungi associated with the disease. Diseased soursop, sweetsop and African star apple fruits (25 each) were collected at random from different retail points and sent to the Plant pathology laboratory for isolation and identification of fungi. This was firstly carried out on water agar and sub-cultured on PDA for seven days. Fungi were identified under a compound microscope based on their morphological and cultural characteristics: colour, growth rate, mycelial and sporulating structures. Healthy fruits each of soursop, sweetsop and African star fruits were surface sterilized and punctured with sterilized cork borer. Pure cultures of isolated fungi were inoculated

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into fruits for test of pathogenicity with plain PDA as control and incubated for one week in the laboratory. The frequency of isolations of fungi associated with rot diseases from 25 samples each of soursops, sweetsops and African star apple fruits were determined by counting the number of times each fungus was isolated from each type fruit. The inhibitory effect of seed extracts from pawpaw, neem and soursop (10 g/100 ml of water) and Zamir fungicide (prochloraz + tebuconazole) amended with PDA (15 ml/150 ml PDA for the plant extracts and 0.45 ml/150 ml PDA for Zamir) on mycelial radial growth of *Aspergillus niger*, *Colletotrichum* sp., *Lasiodipliodа theobromae,* and *Rhizopus stonolifer*, was assessed. Plain PDA was used as control. Six-millimeter mycelial plugs from five-day-old actively growing cultures of the fungi were placed singly on the fungicide amended media in petri dishes. The treatments were arranged in a completely randomized design and incubated at 23 – 25ºC and 70 – 80% RH in the laboratory till the control plate was full. Radial mycelial growth of the fungi was measured daily with a 30 cm ruler and used to calculate percentage inhibition of mycelial growth. Only a few (20%) farmers had knowledge on the extent and causes of postharvest losses associated with the fruit. However (94.4%) retailers had fair knowledge since they encounter most of these losses at their point of sale and during storage. Fruit losses were mainly associated with microbial infections (78.9%) amongst other rot causing factors such as physiological rot due to heat and bruises (66.6%) and wilting (33.3%). In the laboratory studies, soursop and sweetsop fruits were observed to be inflicted by two types of fungal rots (dry and wet) caused by *Lasiodipliodia theobromae, Colletotrichum* spp, *Aspergilus niger* and *Rhizopus stonolifer*. Infection by these organisms on the fruits resulted in colour change from green to colours ranging from brown to dark-brown at any point on the epidermis. Rots associated with African star apple fruits were caused by *Lasiodipliodia theobromae* and *Aspergilus niger*. resulting in dry and shrunken tissues with the colour of diseased tissue changing from the usual pink to brown and dark patches. *Lasiodipliodia theobromae* had the highest frequency of occurrence (40%) on soursop

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fruits, followed by *Colletotrichum* sp. (23.3%), *Rhizopus stonolifer* (23.3%) and *Aspergilus niger* (13.4%). *Lasiodipliodia theobromae* again recorded the highest frequency of occurrence (53.6%) on sweetsop fruits, followed by *Colletotrichum* sp. (28.5%), *Aspergilus niger* (10.7%) and *Rhizopus stonolifer* (7.2%). However, *Aspergilus niger* had the highest frequency of occurrence (56%) as compared to *Lasiodipliodia theobromae* (44%) on African star apple fruits. Soursop seed extract showed the highest efficacy (*in-vitro*) with more than 90% growth inhibition rate on all the tested four fungi, followed by neem seed extract (87.75%), and pawpaw seed extract (83.25%).

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CHAPTER ONE

1.0 INTRODUCTION

Ghana is blessed with favorable natural conditions for agricultural production of diverse crops of which fruit trees are a part. Fruits are the most obvious products of fruit trees and are known for their nutritional benefits to human diet including being good source of vitamins, proteins, minerals, micronutrients and dietary fibers (Teshome *et al*., 2023). Fruit production also contributes to the economic development of a country and is evident in its contribution to the gross domestic product and employment to farmers, traders, processors and transporters through agriculture of which Ghana is no exception (Mensah, 2014).

Fruits trees present in Ghana are mostly exotic (introduced but widely cultivated) such as mango (*Mangifera indica*), sweetsop (*Anona squamosa*), oranges (*Citrus sinensis*), pawpaw (*Carica papaya*) and soursop (*Anona muricata*) (Akosah *et al*., 2021; Bannor *et al*.,2023; Osei *et al*., 2023). Most of these fruits which are commonly available on the markets and are largely consumed, contribute immensely to the economic growth of the country through exports and internal trade. These fruits are however seasonal, and during their off-season indigenous fruits which are native to Africa, where they have originated and evolved over centuries are available. These indigenous fruits have the ability to withstand environmental stress (Cemansky, 2015) and contribute to nutrition even though they are mostly not exported. Fruits such as African star apple (*Chysophyllum albidum*), Golden apple (*Spondias dulcis*), Velvet tamarind ***(Dialium cochinchinense)***, Jackalberry (*Diospyros mesoiliformis*), and Desert date (*Balanites aegyptiaca*) (Achaglinkame *et al*., 2019; Anang *et al*., 2019) are indigenous to Ghana . These fruit crops are mostly produced in the Eastern Region of Ghana and transported to Greater Accra region which

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has a high seller and buyer population trading in fresh produce coming from almost all parts of the country.

Indigenous fruits also contribute to the local economy and are an integral part of traditional medicine, as leaves of some are used as both food and medicine, in addition to playing an important role in African diet (Kranjac-Berisavljevic & Gandaa, 2013; Baldermann *et al*., 2016). They are also known to be part of traditional practices and diets, preserving local biodiversity (Nyadanu & Lowor, 2015).

Sadly, most indigenous fruits face the threat of neglect in all parts of the country. However, even some introduced fruits such as soursop and sweetsop are also neglected and so are not cultivated on a large scale (low commercialization) even in the rural areas. These neglected and underutilized fruit crops (NUFC) receive less or no attention from farmers, agriculture experts/researchers and policy makers and are mostly restricted to subsistent farming (Azam-Ali, 2010; Naveena *et al*., 2016). Notwithstanding the importance of the NUFC to the national economy, less attention has been paid to the constraints that hinder the production of the fruits.

The few available NUFC experience poor pre-harvest and post-harvest handling practices which results in considerable post-harvest losses. This is due to their highly perishable nature therefore reducing their contribution to food security. The perishable nature and physical fragility of Soursop fruit resulted in a 60% post-harvest loss, according to Tovar-Gómez *et al*. (2011). Over 30% postharvest loss of Soursop fruits has been recorded in Ghana by Honger *et al*. (2020). Just like Custard apples, Sweetsops have high climacteric behavior thus, rapid rate of respiration and synthesis of ethylene, all of which quickly reduce fruit quality and commercialization (Jain *et al*., 2019). Additionally, even in industrialized nations, it has been estimated that between 20% and 25% of harvested African star apple fruits are lost during post-harvest handling (Droby, 2006; Zhu,

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2006). This indicates the significant losses of these NUFC to postharvest mishandling and this is likely to be higher in Ghana.

Postharvest losses of fruits are largely due to decay (rots) caused by spoilage organisms, of which fungi are the most predominant. A large number of organisms such as *Alternaria alternata*, *Aspergillus niger, Penicillium* spp*., Rhizopus* spp*., Mucor* spp., *Lasiopidlodia theobroma*e, *Fusarium* spp., *Pestalotiopsis* sp. and *Colletotrichum* spp., have been isolated from fruits like Mango, Pawpaw, Avocado, Soursop, and African star apple in other countries (González-Ruíz *et al*., 2021; Ejimofor *et al*., 2022; Abubakar *et al*., 2023; Gómez-Godínez *et al*., 2024; Udinyiwe & Aghedo, 2024) however a few works have been done on these NUFC in Ghana (Honger *et al*., 2020). Identification of causes of these postharvest fruit losses will aid in the development of a chemical control regime for the disease. There is therefore the need for a comprehensive study on the microorganisms responsible for rots in these fruits to provide new basis for planning strategies for their control.

Control measures such as curing, refrigeration, irradiation, modifying the storage environment and packaging media (Zhang *et al*., 2021) and the use of disinfecting agents have been used to control fruit and vegetable diseases after harvest (Feliziani *et al*., 2016). Some of these methods are, however, not applicable in the areas where these NUFC are cultivated. Synthetic fungicides which are commonly used by the farmers are effective but expensive and misuse of these products have resulted in environmental pollution and the development of resistance by the causal microorganisms (Wu *et al*., 2023) resulting in the development of substitute products for control such the use of plant extracts (Debjani *et al*., 2018).

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Plant extracts also known as botanicals if well-developed, can be used as an alternative or complementary control method due to their antibacterial action, non-phytotoxicity, systemicity, and biodegradability (Lengai *et al*., 2020). This alternative will be less expensive and readily available to farmers since they are the producers of the source of the plant extract. The use of botanicals as antifungal agents is becoming popular and the efficacy of crude extracts from plants such as pawpaw, neem, starflower, dandelion, soursop, custard apple and water melon have been proven against fungi rot in pawpaw, strawberry, mango, tomatoes in some countries (Obinna & Abikoye., 2010; Nabila & Soufiyan, 2019; Hernández-Guerrero *et al*., 2020; Motallebi & Negahban , 2024). A few works have been done on the use of crude plant extracts as antifungal agents in Ghana as shown in studies by Suurbaar *et al*., (2017); Nwaogu *et al*., (2021). There is therefore the need to test some of these plant extracts for their efficacy in the control of postharvest fruit rot of some NUFCs (Soursop, Sweetsop and African star apple). This is to increase their availability on the markets to improve nutrition and livelihoods of the value chain actors.

The objectives of this study are therefore to:

i. Assess the knowledge, perception and experience of farmers and retailers of Soursop, Sweetsop and African star apple on harvest and postharvest losses and their causal factors.
ii. Describe the symptoms of postharvest rot diseases associated with fruits of Soursop, Sweetsop and African star apple and identify the microorganisms causing the rot diseases.
iii. Determine the frequency of occurrence of the fungal pathogens associated with the diseased fruits.
iv. Evaluate the efficacy of seed extracts of Neem, Pawpaw, Soursop, and the synthetic product Zamir (prochloraz + tebuconazole) for control of postharvest rots in the fruits.

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CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Importance of Fruits in Ghana

Fruits are the fleshy, seed-related parts of plants that can be eaten fresh and have a sweet or sour flavor. The most often grown ones include mango, pawpaw, orange, grape, strawberry, banana, lemon, pineapple, apple, and cashew amongst others (Duffrin & Pomper, 2006; Wongnaa, 2013; Muder *et al*., 2022, Yiran *et al*., 2023). There are numerous positive impacts of fruits on the health and wellbeing of humans. Fruits and vegetables provide significant amounts of nutrients, including fiber, vitamins, minerals, proteins, and phytochemicals, which support the body's immune system in preventing illness and maintaining general health (Stephen *et al*., 2023). The World Health Organization (WHO) estimates that, notwithstanding the benefits connected to high consumption of fruits and vegetables, a low intake of fruits and vegetables is responsible for over 1.7 million (2.8%) deaths globally each year (WHO, 2013; Rekhy & McConchie, 2014). WHO suggests consuming more than 400 grams of fruits and vegetables per day to improve overall health and reduce the risk of certain non-communicable diseases, including cardiovascular diseases and certain types of cancer. This translates roughly to 5 portions per day (Rekhy & McConchie, 2014; Ungar *et al*., 2013).

The percentage of Ghanaian teens attending school who consumed enough fruits (35.7%), vegetables (26.8%), and both (27.8%) were found to be very low as compared to the consumption of staple foods (Seidu *et al*., 2021).

The increased awareness of the health benefits associated with the consumption of fruits and vegetables has made the Horticultural sector one of Ghana's most promising agricultural industries. Young people and other underprivileged and vulnerable sections of society can also find

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employment in the area. It has been noted that sliced/cut fruits, especially pawpaw, pineapple, watermelon, apple, and mango, are highly consumed. This increased demand has encouraged the growing and exporting of fruits and vegetables in many countries including in Ghana (Essilfie *et al*., 2023). Ghana is the source of many fresh and dried fruits found in German supermarkets, including citrus fruits, pineapples, mangoes, chiles, and papayas. In Ghana, employment in agriculture accounts for over half of all jobs. Contributing 25% of the nation's GDP, this industry ensures both export revenue and the supply of staple foods (GIZ, 2019).

In terms of jobs, tax income, and foreign exchange, the fruit crop export business has made a significant contribution to Ghana's economic growth since its start several years ago. Smooth cayenne pineapples were the first fresh tropical fruit exported from Ghana in the 1980s; smallholders accounted for almost half of export volumes. Commercial production of passion fruit, bananas, and mangoes for the fresh export market came next. About $59.9 million worth of pineapple, banana, mango, citrus, and papaya are exported; they make up over 73% of all horticulture exports (GEPA, 2016)

In 1987, fresh mangoes were shipped to the United Kingdom from Ghana for the first time but, exports fluctuated a lot over time, mostly because there were not enough fruits available (Abutiate, 1995). However, Ghana has seen significant growth in the past 20 years, exporting a variety of fresh and processed tropical fruit products (banana, mango, pawpaw, pineapple, etc.) to Europe. From 2000 to 2013, Ghana's economy benefited from fruit and vegetable exports to the EU to the tune of over €562 million (Eurostat, 2013) and is likely to increase as the years go by if serious measures are put in place to increase yield and reduce losses.

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2.2 Neglected and Underutilized Fruit Crops in Ghana (NUFCs)

2.2.1 The Neglect of Indigenous Fruits and Some Introduced Fruits in Ghana

Indigenous fruits are those that are native to Africa and have developed over hundreds of years. Fruits such as African star apple (*Chysophyllum albidum*), Golden apple (*Spondias dulcis*), Velvet tamarind (*Dialium cochinchinense*), Jackalberry (*Diospyros mespiliformis*), and Desert date (*Balanites aegyptiaca*) (Achaglinkame *et al*., 2019) are indigenous to Africa. Although they are currently grown in many different places and are very popular, these are different from exotic fruits that were introduced from other continents, including citrus and even mango. The fruits of several native wild trees have been enjoyed by farmers without the need to understand how to properly grow them. Native African food crops, especially native green vegetables and staples, are in danger of going extinct because of negative perceptions that have nothing to do with nutrition (Demi, 2014; Kodzwa *et al*., 2023). Some of the unfavorable perception of indigenous fruits and vegetables include being labeled as famine or poor people's food and being exposed to outdated information (Darkwa, 2013; Demi, 2014). Indigenous African food crops are culturally significant, they provide therapeutic benefits in addition to their cultural significance, which makes it imperative that they be preserved for generations. Serious health and economic problems for both individuals and governments have arisen as a result of the marginalization of indigenous food crops in Africa and the subsequent decline in consumption, which has been linked to the rise and spread of chronic illnesses throughout the continent (Raschke *et al*., 2007; Kankeu *et al*., 2013).

Colonial administration policies, which prioritized the production of export commodities like cocoa and coffee above domestic food crops, contributed and still contributes to reduction in the

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consumption of indigenous foods by causing the disappearance of the majority of indigenous crop species in Ghana (Demi, 2014).

These fruit trees are unique because they can provide essential nutrients that would otherwise be absent from a diet. Apart from offering essential elements such as protein, dietary fiber, and carbohydrate, these wild fruits also provide phytonutrients and minerals that are beneficial to human health. Recent research has shown that wild fruits may be able to cure a number of conditions, such as diabetes, cardiovascular problems, inflammations, and diseases of the digestive and urinary system, due to their high fiber and antioxidant content (Achaglinkame *et al.,* 2019; Abakah *et al*., 2021).

Indigenous fruit trees have unique advantages. Due to their innate adaptation to local soils and temperatures, in many cases, they are more resilient to environmental stressors than introduce species (Cemansky, 2015). Researchers in Africa and other countries are examining the nutritional and ecological advantages of wild trees and how domesticating them may enhance such qualities. Additionally, researchers are determining the genetic variety of the trees and working with producers to guarantee their efficient production, frequently as innovative commodities that have the potential to transform regional agriculture (Leakey, 2012). Unlike exotics, small-holder farmers in Africa do not establish these indigenous fruit trees to quite the same scale (Sileshi *et al*., 2023). For instance, by supporting domesticated breeding programs and planting fruit trees on farms, the World Agroforestry Centre (ICRAF) started the "Trees for Change" campaign to persuade people to abandon wild gathering. Communities interested in starting their own nurseries and raising and domesticating native fruit trees can also receive instruction from the World

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Agroforestry Centre. In order for communities to profit economically and healthily from locally grown fruits, there are also more initiatives that teach farmers value addition and processing techniques (Pichop *et al*., 2016).

2.2.2 Economic importance of indigenous fruits

In some parts of Africa, a wide range of native fruit trees improve the diets and earnings of local populations, particularly during periods of potential household vulnerability (Chivandi *et al*., 2015; Leakey *et al*., 2022). The fruits are either harvested and eaten at home, sold at the market, or processed into juices and jams to add value (Dzokoto & Tempah, 2020). Fruit production is not the only use for many fruit trees. The shade that the homestead's trees give is beneficial to crops. Leaves can be fed to animals or composted. An indigenous tree in Ghana may eventually provide lumber when it is grown for shade and its fruits are sold to make money. There are more medicinal uses for the leaves, fruits, and other parts of the tree (Boadu & Asase, 2017). Tree bark is frequently used to make fiber, while wood is frequently used to make fences, furniture, house poles, and other structures. In addition to generating revenue, native fruit trees are considered low-risk investments due to their minimal capital requirements (Schreckenberg *et al*., 2002).

According to scientists, indigenous fruit and vegetable trees might save millions of lives if they are domesticated and planted on farms. They would give starving children and adults a wholesome food supply and vital vitamins and minerals. (Atuna *et al*., 2022; Sileshi *et al*., 2023). Additionally, planting trees helps restore damaged ecosystems and stop further soil loss and desertification. Namibian rural economies rely heavily on non-timber forest products (NTFPs). In 2004, NTFP contributed N$619 459 000 (U$ 77 432.375) to the national economy directly and indirectly (Mendelsohn *et al*., 2005).

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In Namibia, sale of native fruits accounts for 51.6% of total income, followed by formal employment (12.9%), pensions, wages, and salaries (9.6%), farming (6.5%), and casual work (6.4%). These figures are based on statistics supplied by Elago & Tjaveondja (2015). Indigenous fruits *Strychnos cocculoides* and *Uapaca kirkiana* are widely traded and consumed in Zimbabwe's rural and urban areas, reducing poverty by 30% and producing year-round revenue above the poverty line (Ramadhani, 2002). Research by Dagmar (2004) shows that the sale and consumption of native fruits benefits most rural households. Women sell the fruits and utilize the money they make to buy needs for the home.

Thus, encouraging developing countries such as Ghana to consume more native fruits as well as fruit-based dietary supplements can help to minimize food insecurity in emerging nations. There are, however, some introduced fruits such as Soursop, Sweetsop and African stat apple which are also neglected and so are not cultivated on a large scale (low commercialization) even in the rural areas. These are equally of economic importance to the country

2.3 Characteristics, Uses, Economic Benefits of Soursop, Sweetsop, African Star Apple

2.3.1 Soursop Fruit (*Annona muricata)*

The tree species *Annona muricata,* referred to as Soursop, is indigenous to the tropical areas of the Americas but has been widely introduced into other tropical and subtropical countries including Ghana (Honger *et al.,*2020). In Ghana, Soursop is mostly grown in the Eastern region and is referred to in Ewe as "*evo*", "*aluguntugui*" in Ga and "*aborofontungu*" (Twi) (Osei *et al*., 2023). The biggest fruits of the *Annona* genus are found on *Annona muricata*, the most tropical semi-deciduous tree (Omere *et al*., 2023).

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Soursop belongs to the family Annonaceae. They grow on trees and produce enormous, oval-shaped fruits. Its green, spine-adorned skin hides whitish, fibrous flesh underneath (Moghadamtousi *et al*., 2015; Coria-Téllez *et al*., 2016). Its spiky green fruit is often compared to a strawberry or pineapple because of its rich flavor and creamy texture. Compared to a conventional meal, this fruit is low in calories and high in fiber and vitamin C, among other nutrients. A 3.5-ounce (100g) portion of raw soursop has 66 calories, 1g protein, 16.8g carbs, 3.3 grams of fiber, and 34% of the recommended daily intake of vitamin C. It is possible to receive 8% of the recommended daily intake of potassium, 5% of the recommended daily intake of magnesium, and 5% of the RDI for thiamine (Bhat & Paliyath, 2016). Soursop contains trace levels of iron, riboflavin, folate, and niacin. Nearly every component of the fruit, including the fruit, stem, and leaves, has a medical use. The soursop fruit's skin, pulp, and seeds all possess excellent antioxidant capacity and high nutritional value (Osei *et al*., 2023). The leaves and pulp of the soursop plant from Ghana constitutes essential oils which has promising antioxidant properties and this points to possible uses in the pharmaceutical, cosmetic, and food processing and preservation sectors (Gyesi *et al*., 2019).

Additionally, it may be utilized in cooking. Numerous juice mixes, nectars, syrups, shakes, jams, jellies, preserves, and ice creams are made using soursop pulp (Akonor, 2020).

Traditional medical practitioners utilize soursop to treat a wide range of ailments and conditions. Its rich nutritional profile provides a multitude of health benefits. Through apoptosis induction, immune response enhancement, blood glucose reduction, depression reduction, digestion stimulation, and blood vessel dilatation, the soursop leaf has been found to be effective in suppressing cancer cells (Yahaya *et al*., 2017). Soursop also possesses anticarcinogenic effects,

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antihemorrhagic effects/anticoagulant properties, antidiabetic effects, effect on lowering cholesterol and effect on the blood pressure level in humans (Afzaal *et al*., 2022)

A decoction of young shoots and leaves can be used to treat indigestion, coughs, diarrhea, dysentery, and gall bladder infections. Mashed leaves can be used to treat rheumatism and eczema. There are antispasmodic qualities to the blooms. While the unripe fruit has astringent properties and can be used to cure diarrhea, the ripe fruit prevents scurvy (Elavarasan *et al*., 2014). This study contrasted the effects of soursop with the well-known chemotherapy drug adriamycin. It was shown to destroy cancer cells without harming healthy cells and to be 10,000 times more potent than chemotherapy (Tripathi *et al*, 2014).

The greatest producer of soursop in the world is Mexico (Hernández *et al*., 2013). Currently, 23,715 metric tons are produced annually, valued at around 159,856 million pesos (US $8,295,632). With 1,990 acres cultivated in the municipalities of Compostela (1,912 acres), San Blas (52.4 acres), Bahia de Banderas (12 acres), Tepic (7.16 acres), and Xalisco, Nayarit is the primary location for cultivation of the crop (SIAP 2016). This indicates the possibility of developing countries such as Ghana can also make a significant increase in the country's GDP through increasing the production of soursop fruits.

2.3.1.1 Diseases and pests of soursop

Soursop fruits gathered in the coastal savannah zone of Ghana have been found to be destroyed by two primary diseases, stem-end-rot and anthracnose, which are caused by *Lasiodiplodia theobromae* and *Colletotrichum gloeosporioides*, respectively (Honger *et al*., 2020). The deadliest anthracnose is caused by *Colletotrichum gloeosporioides (Glomerella cingulate*), and it occurs

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most frequently in places with high humidity and rainfall, as well as in arid regions during the rainy season.

Lesions on leaves, fruit, and other plant parts are caused by the pathogen. Ultimately, these lesions develop a concentric ring pattern and turn dark (Sharma & Kulshrestha, 2015). Two diseases that mostly afflict neglected trees are diplodia rot (*Botryodiplodia theobramae*) and black canker (*Phomopsis anonnaccarum*), which result in mummified fruit and purple-to-black lesions. *P. anonnaccarum* and *B. theobramae* create marginal leaf scorch, which causes twig dieback. Fruit with diplodia rot has a deeper, more widespread corky rot and a darker internal discoloration. A soil-borne fungus called *Cylindrocladium colhounin* is the cause of *Cylindrocladium* fruit and leaf stain. It might lead to almost complete fruit loss in years with excessive rains. The fruit first develops little black patches on its shoulders, which later enlarge, dry up, and break as they spread along the sides. The fruit loses its marketability even when the illness is relatively superficial. (Tripathi *et.al*., 2014).

Cham *et al*., (2019) recorded number of insect pests associated with soursop in Mexico which included pink mealybug of hibiscus Hemiptera: Pseudococcidae's *Maconellicoccus hirsutus* (Green) and an armored scale (Hemiptera: Diaspididae) *Pinnaspis* sp. which were among the 20 phytophagous species among the 3,674 insects that were gathered. Twelve predatory species were found in the *Hippodamia convergens* Guérin-Méneville, *Olla v-nigrum*, *Paraneda pallidula guticollis*, *Stethorus pinachi,* and the Coccinellidae (*Azya orbigera*, *Chilocorus* sp., *Cryptolaemus montrouzieri*, *Cycloneda sanguinea* L., *Cycloneda* sp.) and Chrysopidae (*Ceraeochrysa valida*, *Ceraeochrysa* sp., and *Chrysoperla externa*, as well as five parasitoids belonging to the genera *Aphytis, Coccophagus, Encarsia* (all Hymenoptera: Aphelinidae), *Anagyrus*, and *Gyranusoidea* (both Hymenoptera: Encyrtidae). There was also a first record of the ladybird beetle *Paraneda*

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pallidula guticollis in the state of Nayarit with nine phytophagous species that were also new to Mexico's soursop records (Cham *et al*., 2019).

Two significant pests in South American nations are the bephrata wasp and the cerconota moth *(Cerconota anonella)*. These insects cause serious harm to the fruits. Scale insects, carpenter moth larvae, mealybugs, and root grubs are some of the most common insect pests that harm soursop. (Benson *et al*., 2024). Occasionally, the Mediterranean and Oriental fruit flies are observed on matured green fruits. A 0.05 percent Malathion spray, bait traps, or fruit fly traps can be used to combat this. Spraying should be done only in the afternoon to prevent killing pollinating insects (Tripathi *et al.* 2014). Commercial pesticides can be used, but caution must be exercised to avoid destroying beneficial insects during the pollination of flowers. Small insects, bug larvae, and eggs are suffocated by homemade pesticides, such as a cup of vegetable oil in a gallon of water (Dougoud *et al*., 2019).

A high record of insect infestation of soursop and other fruits such as mango, sweet pepper, tropical almond and shea nut was reported by Badii *et al*. (2015) in the northern part of Ghana. These infestations were caused by insects such as *Bactrocera invadens*, *Dacus ciliatus* (Loew) and *Ceratitis cosyra* amongst others (Badii *et al.,* 2015).

Due to the abundance of host plants and the prevalence of various fly species in the ecosystem, special consideration must be given to how these pests affect commercial fruits and how sustainable management plans can be developed to combat these economically significant issues in Ghana.

2.3.2 Sweetsop (*Annona squamosa*)

The tropical American plant known as Sweetsop, or Sugar apple or Sweet apple, is a member of the Annonaceae family and is widely grown for its flavorful, juicy fruit. It is cultivated in Asia, the

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Pacific, Africa, and America (Datiles & Acevedo-Rodríguez, 2022).

The Sweetsop tree grows to a height of 10 to 20 feet (3-6 meters) and has an open crown of uneven branches and zigzag twigs. The deciduous, green, lanceolate leaves have a sharp base and an acuminate tip. It has an acuminate apex and measures 17 cm in length by 3 to 7 cm in breadth (Crane *et al*., 2021). Green flowers can be kept single or in groups of two to three and appear on newly grown wood that is one to three years old. Small flowers seldom ever produce commercially viable fruit; instead, one blossom is often bigger and more robust than the rest. The green flowers feature three sepals above three fleshy petals and are 1.0 to 3.0 cm in length (Crane *et al*., 2021).

The aggregate fruit weighs between 4 and 24 ounces (113-682 grams), has a diameter of 2 to 5 inches (5.1-12.7 cm), and can be heart-shaped, spherical, oval, or conical. When the fruit is mature, its loosely cohering segments which protrude as spherical protuberances are readily detached. Green and purplish-red sugar apples have white or creamy white flesh that tastes sweet and pleasant and has a viscosity similar to custard. The pulp contains a large number of tiny, glossy, dark brown seeds (Crane *et al*., 2006). Many of the segments surround a single oblong-cylindric, black or dark-brown seed that is about 1/2 in (1.25 cm) long. There might be 20 to 38 seeds, or possibly more, in the typical fruit. On the other hand, some trees provide fruit without seeds.

Fruits, stems, bark, and leaves are among the elements of the plant that have historically been used to treat a wide range of illnesses, including inflammatory and gastrointestinal diseases. Its medical significance is highlighted by its lengthy history of usage (Gautam *et al*., 2024). The plant that has a wide variety of phytoconstituents that have important medicinal uses. Among the many bioactive substances found in this plant are alkaloids with cytotoxic, antimicrobial, and antiparasitic qualities, such as annonamine, reticuline, squamocin, annonaine, and annomuricin A (Kumar *et al*, 2021). By inhibiting mitochondrial complex I, acetogenins including squamostatin, squamocin,

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annonacin, and bullatacin in sweetsop are known to have strong cytotoxic effects on cancer cells such as breast cancer (Al-Nemari *et al*., 2022).

In addition to being a great source of vitamins and manganese, sweetsop has relatively little levels of protein, carbohydrate, iron, magnesium, phosphorus, and potassium. (Abd-Elrazek *et al*., 2019). Compared to an orange, its vitamin C content is greater. An elevated risk of coronary heart disease and stroke has long been associated with a high blood level of amino acids. Sweetsop has high magnesium level, and helps reduce the risk of stroke and heart attack (Amao, 2018). Magnesium and Niacin (Datiles & Acevedo-Rodríguez, 2022) in the fruit help to lower cholesterol and keep bones healthy. People who are iron deficient should consume sugar apples because of their iron-rich properties, which aid to heal anemia. Sweetsops are high in fiber. A high-fiber diet has been associated with a lower incidence of type 2 diabetes, and dietary fiber has been shown to reduce the rate of sugar absorption into the body (Suresh *et al*., 2024).

Sweetsop exhibited a respectably high level of antioxidant (free radical scavenging) activity in a study in Ghana by Boakye *et al*. (2015). With the exception of the presence of alkaloids, the fruit extracts generally indicated favorable results for the main phytochemicals examined. These consisted of triterpenoids in African mango pulp and sweetsop, cardiac glycosides in soursop, sweetsop, and African mango seeds, and coumarins in breadfruit and soursop. The inclusion of these fruits in diets may therefore have health benefits, which suggests that their use is necessary to achieve the population's best possible health (Boakye *et al*., 2015)

Although there is a lack of data on sweetsop production, what is known indicates that many nations have a great potential for sweetsop market expansion. Commercial cultivation of this plant is practiced in the USA (Florida), the Middle East, India, Malaysia, Thailand, and the West Indies and Dominican Republic. The Philippines produce most of the fruits in the world, despite the fact that

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it is still mostly consumed domestically and is still regarded as a backyard fruit (Datiles & Acevedo-Rodríguez, 2022). This is similar to Ghana where little to no attention is given to sweetsop fruits. However, with no official statistics on global sweet apple production existing, the crop has a considerable economic impact in the countries where it is grown.

2.3.2.1 Pests and Diseases of Sweetsop

Diseases and pests in *Annona squamosa* have been steadily increasing in recent years, owing to the expansion of the planting area. However, sweetsop faces the challenge of insect pest infestation that causes great damage to the fruits by feeding on the roots, stem, leaves and stem. Fruit borer *(Cerconota anonella, and* Lepidoptera: Oecophoridae*)* is one of the most important pest species of Annona, and *Annona squamosa* is no exception (Silva *et al*., 2017). In addition, the Moth borer (*Anonaepestis bengalella*), root grub (*Anomala* sp.) mealybugs, and coffee carpenter moth (*Zeuzera coffeae*) have been reported to infest *Annona squamosa* (Datiles & Acevedo-Rodríguez, 2022).

The most common pollinators of atemoyas and sugar apples are nitidulid beetles, often known as sap beetles, which breed and feed in sap flows or decomposing fruit. The sweet, fermenting smell of *Annona* blossoms attracts bugs (Pena & Crane, 2006). The most prevalent pests on sweetsop in Florida are ambrosia beetles and annona seed borer. One by one, the female wasps deposit their eggs in tiny, immature fruits with the annona seed borer. The larvae pupate inside the seed after consuming its endosperm. By burrowing through the fruit's shell, adult wasps cause fungal infection and mummification of the fruit (Pena *et al*., 2002; Velez-Gavilan, 2022).

In order to introduce the symbiotic ambrosial fungus and produce a brood, female ambrosia beetles dig a network of tunnels in the wood or pith of sensitive woody plant twigs, branches, or short

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trunks. The beetles remain with the brood until they mature and consume the fungus. Males are little, rare, haploid, and unable to fly. Females mate with their male partners before attacking a new host. The majority of attack on live plants take place at bark wounds on bigger trees or close to ground level on saplings. A young tree may perish if a lot of insects attempt to colonize it. Sometimes isolated attacks go unnoticed. Conversely, cankers may grow when a single attack occurs and eventually overtakes the tree (Atkinson *et al*., 2000).

Numerous fungi can produce dry fruit rot or fruit mummification. Fruit may stay on the tree for a while after turning purplish-black to black. These fungi often invade fruit following the adult annona seed borer's emergence from the fruit. These fruit rots caused by fungi attack occur pre and postharvest of the fruits (Crane *et al*., 2005). The most common diseases affecting Florida sweetsop crops are rust *(Phakopsora cherimoliae)* and anthracnose *(Colletotrichum gloeosporioides)*. The fungus *Colletotrichum gloeosporioides*, which causes anthracnose, infects the fruit, leaves, and flowers. The dark sores that form on the petals of infected flowers proliferate till they become black and die. Infected young fruit will decay and mummify on the tree (Jesse, 2023).

2.3.3 African Star Apple (*Chrysophyllum albidum)*

The *Chrysophyllum albidum* G.Don Holl. (Sapotaceae) tree is widely distributed throughout tropical Central, East, and West Africa, and its bitter-sour edible fruits have a wide range of ethnomedical uses (Amusa *et al*., 2003; Odeyemi & Fawole, 2022). Ghana and south Nigeria are major consumers of the African star apple. Its maximum height and width are 25 to 37 meters and 1.5 to 2 meters, respectively (Dadegnon *et al*., 2015). When completely ripe, the fruit has an ovoid to subglobose form, a pointed tip, with a maximum length of 6 cm and a maximum width of 5 cm. It is only readily available from December to March, which is the summer season. When ripe, the skin or peel transforms from orange to golden yellow, while the pulp within the peel may be light

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yellow, pink, or orange. There are three to five inedible seeds in the pulp (Emudainohwo *et al*., 2015). Reports given (Dzokoto & Tempah, 2020) shows that it may be used to make jams and jellies that rival those made with raspberries, the fruit has enormous economic potential. The fleshy fruit pulp is a popular snack among Ghanaians of all ages and may be used to make jams.

In folklore, the succulent pulp is frequently eaten and is believed to aid in the treatment of diabetes. For generations, the bark of the plant has been used to cure yellow fever and malaria, while its leaves have been utilized as a palliative remedy for diarrhea and stomachaches (Abolaji & Adiaha, 2015). Throughout southern Nigeria, the leaves, barks, and roots are frequently used to heal bruises, sprains, and wounds. It has a remarkably high level of vitamin C, or ascorbic acid. Its leaf extract has hypoglycemic (to cure diabetes) and anti-platelet properties, and it may operate as a natural antioxidant booster to eliminate free radicals from oxidative stress illnesses, yet it also has harmful effects on certain organs (Asare *et al*., 2015).

The root and seed extracts help to accelerate the healing process by halting bleeding from newly opened wounds and avoiding infection. This shows that the cotyledon of the seed contains anti-hyperglycemic and hypolipidemic characteristics. It is also possible to convert fresh fruit pulp into jam, syrup, stewed fruit, soft drinks, and jellies (Ajayi *et al*., 2020). The cotyledons of *Chrysophyllum albidum* seeds are an excellent source of nutrients, and has substantial levels of carbohydrate. The seeds have low moisture content and are not susceptible to microbial degradation and spoiling, meaning that they can be kept for a respectable amount of time (Tsado *et al*., 2023).

The pulp and peels of the fruit contain phytochemicals such as lactic acid, acetic acid, carbohydrates, proteins and vitamin C (Asare *et al*., 2015). The fruit pulp of the African star apple

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has higher levels of iron and ascorbic acid than other edible fruits (Akubugwo & Ugbogu, 2007; Oguntimehin *et al*., 2022).

A study by Bolanle-Ojo & Onyekwelu, (2014) and Danladi *et al*. (2023) found that *C. albidum* makes a substantial contribution to household income in both of the study environments (derived savannah and rain forest). This is consistent with (Nemapare *et al*., 2024) findings that in Zimbabwe, indigenous fruits are the main source of household income for women and children. African star apple sales have the potential to be a substantial source of income for rural communities (Danladi *et al*., 2023). Through tree selection and domestication, increased fruit yield will result in higher revenue, raising the living standards of rural residents.

2.3.3.1 Pests and Diseases of the African star apple

Insect pests severely harm African star apples throughout the fruiting season and during storage. Insect pests such as Drosophila spp. (Diptera; Drosophilidae) and *Ceratitis capitata* Weid (Diptera; Tephritidae) are responsible for causing damage to African star apple (Ugwu & Umeh, 2015).

Studies have shown that fungi associated with rot in African star fruits include *Botryodiplodia theobromae, Rhizopus stolonifer, Aspergillus niger, Penicillium* spp., *A. tamarii, A. flavus, Geotrichum* spp., *Fusarium* spp., *Saccharomyces* spp., *Penicilium* spp. and *Trichoderma* spp. (Amusa *et al.,* 2003; Udinyiwe & Aghedo, 2024). Certain bacteria species such as *Bacillus cereus, B. polymyxa, Escherichia coli, Proteus mirabilis, Klebsiella* spp., *Flavobacterium* spp., *Serratia* spp., *Pseudomonas aeruginosa* and *Staphylococcus aureus* can also contribute to rot in the fruits (Aroptupin *et al*., 2016; Udinyiwe & Aghedo 2024).

A market survey found that the fruits frequently degrade within five days, beginning with a shift in color from a uniform orange to one with patches and ending with the fruit shrinking (Adebisi,

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1997). This is mostly caused by microbial infection. The effect of these microbial attacks significantly reduces the phytochemical properties in the fruit (Aroptupin *et al*., 2016). It also causes a high level of contamination to the fruits during postharvest thereby making it unappealing to consumers and reducing its marketability.

2.4 Post harvest losses of fruits in Ghana

2.4.1 Basic concepts of postharvest loss of fruits

Fresh produce of fruits, vegetables, and root crops (perishable crop produce) are all live biological plant organs that are not dead but respire comparable to that of animals (Paltrinieri, 2016). Throughout the post-harvest handling system of the distribution chain of perishables, both quantitative and qualitative losses take place (from harvesting through processing, packaging, storage, and transportation to the ultimate delivery of the fresh food to the customer) (Sugri *et al.,* 2021). There are many factors that affect postharvest losses, and they differ greatly from place to place. Fruits and vegetables undergo active decomposition processes following harvest (Yadav *et al*., 2023). Until the crop is no longer marketable, a number of biochemical processes progressively change its original makeup. Postharvest shelf life is often calculated by objective methods that evaluate the overall appearance, flavor, texture, and taste of the product.

In Ghana, typically postharvest losses account for 20 to 25 percent of the 20 million metric tons of food produced. According to conservative estimates, postharvest agricultural losses in Ghana range from 10% to 50%, with perishables suffering the greatest losses (Kporvie, 2020). Harvested produce is extremely vulnerable to physical damage and deterioration during the handling process (Ridolfi *et al*., 2018). Approximately 30% of grains, 40% to 50% of root crops, fruits, and vegetables, 20% of oilseeds, meat, and dairy products, and 35% of fish are lost or wasted globally each year.

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Different produce experiences different kinds of losses, which are mostly dictated by the type of produce, the marketing time, and the producing location (Sawicka, 2020). There are disparities in the statistics on production losses as a result of the many approaches taken to calculate losses and the infrequent publication of these approaches (Kader, 2002). Nearly half of the losses are thought to be caused by improper handling and physical harm during distribution and storage (Cortez *et al*., 2002).

It is necessary to carefully coordinate and integrate all postharvest stages and procedures from harvest to consumer level in order to handle products like indigenous fruit crops. It should be considered that every incidence of product being mistreated affects its quality in some manner. When consumers are selecting fruits, factors such as colour and appearance, texture, flavour, and nutritional value all play a role. (Barrett *et al.,* 2012; Mihafu *et al*., 2020). Fruits are considered to be of high quality when they are devoid of defects, physiological conditions, mechanical damage, water loss, and rotting (Amartey, 2013).

2.4.2 Causes of postharvest losses

Postharvest losses in the horticultural production chain are a challenge in both developing and developed countries (Ridolfi *et al.*, 2018; Karoney *et al.*, 2024). In developing countries, small scale fruit farming is essential for increasing income, reducing poverty, and enhancing rural communities' access to food and means of subsistence (Ridolfi *et al.*, 2018; Sugri *et al.*, 2021). Losses of at least 30% are anticipated in emerging nations, especially those in Sub-Saharan Africa (Sibanda & Workneh, 2020; Stathers & Mvumi, 2020). Postharvest losses impact the aesthetic appeal of the fruit and, consequently, its market value in addition to its quality and quantity (Sibanda & Workneh, 2020; Stathers & Mvumi, 2020; Karoney *et al.*, 2024).

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Any decline in the wholesomeness, availability, edibility, or quality of food that inhibits its eating is referred to as post-harvest loss (Karoney *et al.*, 2024; Nath *et al.*, 2024). From harvesting to handling, storage, processing, and marketing to final consumer delivery, Amoako-Adusei (2020) recorded high quantitative and qualitative losses of tomatoes at every step of the post-harvest system in Ghana. Key factors contributing to postharvest losses in the nation include poverty, inadequate post-harvest management, a lack of suitable processing and storage facilities, inadequate infrastructure, and inefficient marketing tactics (Sugri *et al.*, 2021).

Insufficient storage and marketing facilities force farmers to sell their goods at throwaway prices resulting in economic losses (Faibil *et al.*, 2021). Due to overprocessing, packaging, and marketing, the majority of losses happen at the end of the food chain (FAO, 2008). Farmers can calculate postharvest losses in absolute terms for produce lost after harvest to compute postharvest losses as a proportion of total produced quantity (Ridolfi *et al*., 2018). Preventing the same quantity of fruit loss is more costly than controlling and/or minimizing postharvest losses. Postharvest management has an impact not just on food safety and quality but also on competitive edge on the market (Ansah *et al.*, 2018).

There are no long-term postharvest management options in the horticultural supply networks of developing countries (Ansah *et al.*, 2018; Bisht & Singh, 2024). According to reports, the commodities, their condition at the time of collection, the distance traveled, and the road network all contributes to the rate of postharvest loss (Kerreth *et al*., 2013; Abubarkar *et al.,* 2023). Harvesting and post-harvest practices that are not done correctly lead to food spoiling and quality losses, including changes in appearance, flavour, and nutritional value (Yahia *et al.*, 2019). Postharvest management becomes difficult when produce is not handled, transported, stored, processed, and packed effectively (Sugri *et al*., 2021).

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2.5 Pre-Harvest and Postharvest Activities Contributing to Fruit Loss

2.5.1 Pre- harvest factors

The basis for post-harvest management is pre-harvest management (Fekadu & Andarege, 2024). Once fresh fruits are harvested, their overall quality cannot be enhanced, but it may be preserved. The ultimate market worth of the product and customer acceptability are determined by the ability of the farmer to apply the highest of quality pre-harvest technology, harvest, and then use the best post-harvest handling techniques (Dichi, 2018). Pre-harvest factors that impact postharvest quality include frequent irrigation, fertilizer application, pest control, growth regulators, climatic conditions like rainy and windy weather, natural climates like hailing, high wind velocity, and heavy rainfall, and tree conditions (Ofosu *et al.*, 2023; Fekadu & Andarege, 2024). These factors change the physical and chemical composition of fruits, which impacts overall fruit quality and storage suitability (Barman *et al*., 2015; Abu, 2021).

2.5.2 Cultural operations

The photosynthetic capacity of leaves is influenced by the rate of light exposure; dark areas of the canopy receive less light and need more leaves than well-lit areas for optimum fruit development. To directly or indirectly affect photosynthesis and sink activity (fruit growth), growers can employ a range of techniques. Important factors include: tree height, distance, fruit thinning, pruning, fertilizer, growth regulator treatment, watering, and phytosanitary practice (Ofosu *et al.*, 2023; Fekadu & Andarege, 2024). Intense pruning increases the root/shoot ratio, which promotes vegetative development by decreasing leaf area, whole-tree photosynthesis, and photosynthetic transfer to fruits and roots (Dichi, 2018).

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2.5.3 Soil operations

Promoting the health and quality of the soil is the main goal of organic agricultural methods. When the right levels of plant nutrients are accessible to the vegetables during the growing season, they are guaranteed to be of the best quality when they are packed and distributed (Darfour & Rosentrater, 2022; Osabohien, 2024). And consequently, achieving this objective will progressively enhance the postharvest quality of cultivated vegetables. The presence or absence of a certain nutrient in a plant can either enhance or reduce its sensitivity and have a positive or negative impact on its composition. The ideal soil nutrient levels for postharvest quality may differ from those that offer the maximum yields while maximizing soil fertility (Darfour & Rosentrater, 2022; Osabohien, 2024). Nitrogen (N) and potassium (K) are very important for the growth of a healthy plant (Darfour & Rosentrater, 2022).

2.5.4 Climatic conditions

The quality and nutritional value of fruits and vegetables are impacted by changes in the climate (Baffour-Ata *et al.*, 2021). This also influences the quantity of riboflavin, thiamine, carotene, ascorbic acid, and flavonoids in plants according to the time and location of cultivation (BaffourAta *et al.*, 2021). As light intensity drops, plant tissues' ascorbic acid content falls as well. Temperature affects how quickly plants absorb and use nutrients because increases in temperature generates more transpiration (Srivastava, 2019). Rainfall affects the ability to get water, which might leave plants susceptible to mechanical damage during handling and harvest.

2.5.5 Genetic factors

Important factors include the fruit variety and cultivars. This affects variation in things like the acidity and soluble solids content of the fruit (Neme *et al.*, 2021). Fruit quality and safety after

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harvest may be improved and maintained with the use of biotechnology and horticultural breeding (Yahia & Carrillo-Lopez, 2018; Neme *et al.*, 2021). In addition, gardeners can choose their favourite varieties before planting crops.

2.5.6 Maturity at harvest in relation to quality

When fruits are allowed to ripen on the plant before harvesting, almost all of it tastes excellent. In contrast, certain fruits are harvested before they are mature in order to withstand long-distance shipment and post-harvest handling conditions. This depends on whether the fruit is collected for storage or for immediate consumption.

2.5.7 Method of harvesting

The harvesting technique affects the overall composition and quality of fruits and vegetables by influencing the degree of physiological damage and maturity variety (Sibanda & Workneh, 2020; Stathers & Mvumi, 2020; Karoney *et al.*, 2024). Mechanical injuries like cuts, bruising, and surface abrasions may increase susceptibility to bacteria that cause decay and hasten the loss of water and vitamin C (Karoney *et al.*, 2024). The incidence and severity of such accidents are influenced by the harvesting method (manual vs. mechanized) and the management of the harvesting and handling processes.

The following techniques can be used to harvest fruits;

(a) Hand by pulling or twisting individual fruit pedicel

(b) The use of clippers/secateurs/scissors to harvest fruits singly or in bunches

(c) The use of machines designed for harvesting.

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2.6 Factors Affecting Quality of Fruits after Harvest

2.6.1 Precooling

Precooling is done to remove field heat from freshly harvested vegetables before transport or storage to limit the rate of degradation and metabolism. After harvest, fruit loses quality because of physiological and biological processes that are influenced by product temperature (Duan *et al.*, 2020). Since the profitability of the horticultural sector depends on market quality, fruits must be promptly cooled. It is essential for the first phase of the cold chain and for perishables (Sibanda & Workneh, 2020). There is a distinction between pre-cooling and cold storage, even though food can be preserved in cold storage for this purpose. By inhibiting the growth of bacteria that cause decay, restricting enzymatic and respiratory activity, and minimizing water loss throughout the ethylene generation process, pre-cooling preserves product quality (Duan *et al.*, 2020; Sibanda & Workneh, 2020).

2.6.2 Washing, sorting and grading

It is important to treat fruits and vegetables with care before packing them for transportation. It is common practice to wash crops in order to remove dirt that has stuck to them. Vegetables and fruits handled with dangerous chemicals need to be carefully cleaned before packing. The increased bruising and mechanical damage brought on by rough handling of the products during sorting and grading when preparing fresh fruits for the market are the reasons for losses. An ineffective transportation system makes crops even more vulnerable to decay and microbial growth. (Ansah *et al.*, 2018). For the produce to fetch a good price, it is separated into different grades and attractive shapes. Sorting fruits and vegetables during postharvest treatment inhibits infectious microorganisms from moving from damaged to healthy fruits. Produce is graded by farmers and

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merchants to assist them classify fruits and vegetables using a uniform criterion, which makes managing them easier (Arah *et al*., 2016). To prevent the spread of ethylene, which might cause all the fruits to ripen, it is helpful to grade the fruits according to colour or maturity level. Time lost while harvesting and grading causes heat to accumulate on farms, hastening the aging process (Ansah *et al.*, 2018).

2.6.3 Concept of packing and packaging materials

When evaluating postharvest loss in fruits and vegetables, packaging is one of the most important factors to take into account. Foods are shielded from environmental factors including physical contamination, mechanical harm, and biological and chemical causes via packing (Faibil *et al.*, 2021). The main advantage of packaging is that it shields fresh goods from physical harm brought on by careless handling and delivery. Farmers sell their produce in wholesale marketplaces and fresh markets. Fresh food is frequently offered for sale at the market or retail level without any kind of wrapping. Fruits and vegetables have a much shorter shelf life at room temperature, often ranging from a few hours to a few weeks, if they are not sold in a timely manner (Kporvie, 2020).

Fresh produce and fruit packaging minimize food waste by creating better and more effective packaging that will prolong freshness of the food (Elik *et al.*, 2019). Most developing nations employ cardboard boxes, plastic crates, wooden crates, woven palm baskets, nylon and jute sacks, and polythene bags as common packaging materials (Bisht & Singh, 2024). The majority of the materials listed for packing do not offer complete protection for the product. The two most popular fruit packing methods in many developing nations, especially in Africa, are the wooden box and the woven palm basket (Mibulo *et al.*, 2020; Tapsoba *et al.*, 2022). The height of the wooden box

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is its primary drawback, as it puts a lot of compressive strain on the fruits toward the bottom of the container (Mibulo *et al.*, 2020; Tapsoba *et al.*, 2022).

Additional benefits may be obtained from packing; barrier protection is utilized to keep pollutants like dust and germs out of the environment. Using packs makes handling small quantities of goods quicker and easier than carrying them unpackaged. It also makes better use of available space for transit and storage. Different levels of protection must be included in the package due to susceptibility to different types of damage. The choice of packing material, which may be the most important factor in identifying the kind of packaging needed, will be influenced by issues such as microbial infections, vulnerability to water loss, or heat buildup.

2.6.4 Temperature

The environmental factor of temperature affects how long fresh fruits may be stored. Even after harvest, fruits continue through all the physiological processes, such as respiration and transpiration, but because they are not connected to the parent plant, they do not get water or nutrients (Yahia *et al.*, 2019). Produce starts to lose its nutritional value, weight, taste, and texture. Despite the fact that these processes are unavoidable, they may be significantly controlled by closely monitoring the temperature and relative humidity during fruit storage or transportation. In order to improve fruit quality and minimize chilling damage, low temperature conditioning is a more effective method than heat treatment (Yahia *et al.*, 2019; Stathers & Mvumi, 2020). At sufficiently low temperatures, the development and multiplication of many disease-causing bacteria are inhibited. Among other things, temperature can regulate the rate of respiration.

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2.6.5 Storage conditions

Storage, which includes preserving and preserving food from the point of production to the point of consumption, is an essential marketing function. Sufficient facilities, cleanliness, and monitoring are necessary for long-term storage to be successful. Controlling humidity, temperature, and cleanliness is particularly important in closed buildings, such as silos, granaries, warehouses, and hermetic bins (Yahia *et al.*, 2019; Stathers & Mvumi, 2020). Facilities can degrade due to pests (rodents, insects) and molds, which can lead to losses in both quantity and quality. The majority of fruits and vegetables are difficult to store at room temperature for extended periods of time due to their high moisture content. Storage ensures a consistent supply of products throughout the year and prolongs the processing season (Yahia *et al.*, 2019; Stathers & Mvumi, 2020).

2.6.6 Transportation

A lack of refrigerated transportation, inadequate transportation techniques, and poor infrastructure (roads, bridges, etc.) are the main challenges in the transportation stage of the supply chain. Horticulture crops cannot be transported on roads in the majority of developing countries. Additionally, there are not many transportation vehicles or other means of conveyance, especially those that are most suited for perishable commodities (Gandaa, 2022) For both local and foreign marketing, this is accurate. Due to their small holdings, most farmers cannot afford transport vehicles. While some fresh product marketing companies have been able to acquire transport trucks, they have not been able to improve the awful state of the roads (Tapsoba *et al.*, 2022).

The length of transportation and the state of the roads both have an impact on the quality of fresh products. More contact and bruising occur on rough road and hilly areas than on smooth ones. The duration of the trip has an impact on the quality of the conveyance as well. A refrigerated van does

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not have to be driven constantly. It not only makes products more expensive, but it also makes them of inferior quality (Dichi, 2018). Donkeys, hired trucks, lorries, fuel tankers, articulator trucks, buses, pick-up vans, public transportation, and human labour are a few examples of modes of transportation (Gandaa, 2022; Tapsoba *et al.*, 2022). Fruit transportation should avoid excessive movement and vibration. It is important to stack and wrap the fruit well. These adverse circumstances during transit lead to substantial losses since the road networks in the majority of developing nations are in poor shape.

2.7 Postharvest Treatment Technique for Fruits

It is important to take into account how long fruits are exposed to this temperature. The temperature should be just low enough to render biological composition inactive during cold treatment, but care should be made to prevent freezing the water that the cells contain (Yahia *et al.*, 2019; Stathers & Mvumi, 2020). This may be achieved by submerging the fruit in water when applying heat. While appearance, texture, flavour, and nutritional value are still considered traditional criteria for fresh fruit quality, traceability, safety from chemicals, microbes, and toxicology, and other factors are becoming more and more important for all parties involved in the supply chain, from the farm to the consumer. Microbes grow and react with product to induce contamination, which can lead to degradation and losses at any stage of the post-harvest chain because of the supply chain's numerous unknowns. Therefore, in order to avoid microbial and pathogenic contamination of fruit and vegetables, postharvest losses must be controlled (Ofosu *et al.*, 2023; Fekadu & Andarege, 2024). Many postharvest physical, chemical, and gaseous treatments can be applied to maintain fresh freshness with high nutritional content and to satisfy fresh produce safety regulations (Ofosu

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et al., 2023; Fekadu & Andarege, 2024). Usually, these postharvest procedures are combined with appropriate storage temperature control.

2.7.1 Thermal treatment

Thermal treatment is the process of reducing the biological response in produce by exposing it to either heat or cold for a certain amount of time. Saturated water vapor heat, hot water dip, hot dry air, and brushing during hot water rinse are a few of the treatment (Yahia *et al.*, 2019; Stathers & Mvumi, 2020). Benefits of these heat treatments include decreasing the rate of fungal rot, eliminating the insects that produce it, and using heat to inactivate the enzymes that create it. The heat used to kill fungus must be strong enough to kill molds and spores, but not so high that it causes oxidation, the Maillard reaction, or caramelization in fruits. It is important to take into account how long fruits are exposed to this temperature. The temperature should be just low enough to render the biological content inactive during cold treatment, but care should be made to prevent freezing the water that the cells contain. This may be achieved by submerging the fruit in water when applying heat (Yahia *et al.*, 2019; Stathers & Mvumi, 2020).

2.7.2 Edible coating

An edible coat has to have certain qualities, such creating a uniform layer of protection or coating on the fruit's surface, allowing and/or regulating the pace of fruit respiration to preserve its sensory quality, being inert and safe for human consumption, being simple to apply, and drying rapidly (Nxumalo, 2023). Edible coatings strengthen the waxy cuticle and restore or replace the cuticle's damaged natural defenses (Nxumalo, 2023). Fresh produce with edible coatings helps to reduce moisture loss during storage by partially blocking moisture from moving to the surface of the product (Olunusi *et al.*, 2024). Nevertheless, a gas barrier that modifies the atmosphere surrounding

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the produce reduces respiration, senescence, and enzyme oxidation while maintaining the texture and color of the product.

Additionally, it contains active or functional substances like as antioxidants, flavoring and coloring agents, nutraceuticals, and antimicrobials that will preserve the quality and safety of produce, as well as preserve the product's structure and guard against mechanical damage (Nxumalo, 2023; Olunusi *et al.*, 2024). Applying an edible packaging involves either submerging the item in the coating solution or sprinkling it with compressed air (Nxumalo, 2023; Olunusi *et al.*, 2024).

2.7.3 Irradiation

Similar to the technology used in pasteurization, fruit and vegetable irradiation is a method of preserving and keeping food safe. One of the most practical physical treatments for postharvest diseases, aside from chemical treatment, appears to be irradiation. Fungicides cannot match the penetration strength, uniformity, and derived effectiveness of radiation in inactivating pathogens.

A great postharvest method for destroying bacteria, molds, and yeasts that cause food to spoil as well as parasite and insect damage, radiation reduces loss during storage, extends shelf life, and improves microbiological and parasitological food safety (Mayanja & Oluk, 2023; Mshelia *et al.*, 2023).

When food is exposed to radiation, it absorbs chemicals and breaks down chemical bonds, including DNA, from rays and e-beams, which are high-energy electrons. Cobalt-60 or Caesium137 radiation, as well as machine-generated electron beams, can assist prolong the shelf life of fresh products.

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2.7.4 Chemical treatment

The maturation and senescence processes in fruits and vegetables have been hastened by the application of chemicals. Their use ranges from inorganic acquired salts to a variety of organic compounds that have been shown to impact the metabolism of plant tissue.

Fresh fruit and vegetables are treated with chemicals such as nitric oxide, sulfur dioxide, and antimicrobial and anti-browning compounds (Ridolfi *et al.*, 2018). Fruit and vegetable ripening and senescence are two of the numerous physiological procedures that are influenced by the extremely reactive free radical gas nitric oxide (NO) (Ridolfi *et al.*, 2018; Stathers & Mvumi, 2020; Sugri *et al.*, 2021). The option of preserving safety is offered by antimicrobial and anti-browning substances, which are separated into chemical and natural/bio-based agents. Chemical-based agents that can be utilized include peroxyacetic acid (PAA), electrolyzed water, hydrogen peroxide (H_2O_2), chlorine-based solutions, and organic acids (Stathers & Mvumi, 2020; Sugri *et al.*, 2021). Grapes are frequently treated with sulfur dioxide (SO_2) to avoid storage degradation. This can be done by delayed release from sodium metabisulfite-based packaging or by first fumigating the field and then weekly fumigating the storage chamber (Yuan *et al*., 2022). Other fruits have also been subjected to SO_2 technology for postharvest deterioration management (Daniel-Swartland *et al.*, 2024). These chemicals are typically administered by spraying or soaking the substance in a solution. The components must not alter the product's organoleptic properties in any way, nor should they endanger human health in any way after ingestion.

2.7.5 Modified atmospheres and gas application

Among the post-harvest techniques that are often recognized are gas application, atmosphere modification and controlled atmosphere (Ridolfi *et al.*, 2018; Sugri *et al.*, 2021). Fruit appearance

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and texture are influenced by the use of these gases, but flavor and odor impacts are rarely given much thought and may differ from product to product. Protective gases can reduce microbial activity and oxidative changes within food products by dislodging the surrounding environment. Food can be packed in a protected gas atmosphere to extend its shelf life by three times its usual value. It is usual practice to employ carbon dioxide, nitrogen, oxygen, argon, and mixtures of these gases.

Packaging with a modified atmosphere is employed based on the product type. Oxygen (O_2) in the package's headspace is often decreased throughout the alteration procedure. Carbon dioxide (CO_2) or nitrogen (N_2), a comparatively inert gas, can be used in place of oxygen (CO_2). Fresh produce has an ideal range of O_2 and CO_2 to maintain freshness and extend shelf life, which might vary depending on whether the produce is sliced up or whole (Ridolfi *et al.*, 2018; Stathers & Mvumi, 2020; Sugri *et al.*, 2021).

2.7.6 Treatment combination

The quality and storage life of produce can be improved when two or more of the post-harvest methods mentioned above are applied in tandem. The application sequence and rate of the rate affect how successful the final outcome will be (Mahajan *et al*., 2017).

2.8 The Use of Botanicals to Control Fungal Rot on Fruits

In agriculture, a variety of fungicides and bactericides are used to manage plant diseases. This has caused public concern due to its harmful effects on the ecology and its carcinogenic nature (Wu *et al*., 2023). Bioactive compounds made from plant extracts might therefore be utilized to fight infections (Ngegba *et al*., 2022).

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Various organic solvents and plant extracts with antimicrobial agents and therapeutic properties, as well as the methods used to extract them, have been studied and documented by several researchers (Ebisa & Tamiru, 2023; Cobbinah *et al.*, 2024). Studies have shown that certain secondary metabolites from plants, such as volatile compounds and essential oils, have a biocidal impact on diseases that develop in produce after harvest (Alvarez-Garcia *et al.*, 2023, Zulu *et al.*, 2023). Additionally, essential oils prevent a number of fungal species from producing mycotoxin (Sivakumar & Bautista-Banos, 2014). All plant components, including the stems, leaves, roots, flowers, fruits, and seeds, consist of alkaloids, steroids, flavonoids, saponins, phenolic compounds, terpenoids, and other secondary metabolites (Parameswari e*t al*., 2019; Sha'a *et al*., 2019). Africa has a very low use of medicinal plants and plant extracts for crop protection and preservation when compared to nations like China and India (Van, 2020).

Plant extracts have the potential to inhibit the growth of phytopathogenic fungi by possessing a variety of chemicals. A large number of plant extracts include antifungal compounds. The development of resistance may be delayed if these psychoactive substances have different mechanisms of action. The use of plant extracts may therefore aid in halting the emergence of antimicrobial resistance (Shuping & Eloff, 2017). Numerous studies utilized plant extracts from papaya, neem, soursop, mango, and custard apple to combat the fungus that cause fruit rot. (Odusola *et al*., 2022). Plant extracts such as pawpaw extract has proven fungitoxic against a number of fungi associated with rot on including *Colletotrichum* spp. (Viana *et al*., 2020). Again, soursop extract and pawpaw extract reduced the activities of *C. fructicola* and *N. haematococca* on mango and soursop respectively in research by Hernández-Guerrero *et al*. (2020).

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CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Assessment of the knowledge, perception and experience of farmers and retailers of soursop, sweetsop and African star apple in the Eastern and Greater Accra Regions on harvest and postharvest losses and their causal factors

A questionnaire survey was carried out at the farmer level in the Eastern region and retail level (selected markets and grocery shops) in the Greater Accra region to obtain information on postharvest losses incurred in the harvest and handling of Soursop, Sweetsop and African star apple fruits.

Discussions with some MoFA district officers of Agriculture in the two regions showed that there are a few to no established farms for these neglected and underutilized fruit crops in Ghana but trees are normally found in people's backyard, gardens and some used as shade crops on farms. Using snowball sampling, one commercial soursop farmer was however, identified and interviewed at Kwasi-doi (Akuapim district) in the Eastern region with four other soursop farmers who had five or more fruit trees at Nsawam and Suhum all in the Eastern region. Farmers (10) who owned more than five African star fruit trees were also identified and interviewed at Akote, Kumikrom, Mamfe Nkwanta, Amanhyia also in the Eastern region. The plants are normally used as shade crops on their farms and in their homes hence are not cultivated on typical farms. Similar situation applied to sweetsop fruits where five farmers were interviewed at Asesewa and Kpong in the Eastern region.

The markets selected on authoritative sampling included Madina, Ashaiman, and Agbogbloshie market and grocery shops around these areas. These three markets are some of the big and major ones in the Greater Accra region with high seller and buyer populations trading in fresh produce

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coming from almost all parts of the country. Purposive sampling was used to select ninety (90) retailers for the study (30 selected within each market and grocery shops).

In all, there were 110 respondents involved; 20 farmers and 90 retailers.

Questionnaires with open and closed – ended questions were designed, pretested and administered to farmers and retailers who traded in Soursop, Sweetsop and African star apple (Appendix).

Areas covered by the questionnaire included:

- Experience in agronomic practices
- Harvest practices and estimated losses
- Postharvest practices and estimated losses
- Knowledge on pests and diseases
- Sources of fresh fruits for retailing and estimated losses
- Storage, nature of losses and estimated losses

Data from the survey was analyzed using IBM Statistical Package for the Social Scientist software version 24. The results were presented in percentages in tabular form.

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3.2 Description of the symptoms of postharvest rot diseases associated with fruits of soursop, sweetsop and African star apple and identification of the microorganisms causing the rot diseases

3.2.1 Description of symptoms of postharvest rot disease associated with the fruits and identification of microorganisms causing the diseases

This was done by visual observation of colour and feeling of diseased tissue with fingers for texture while noting the fungus/fungi associated with the disease.

3.2.2 Identification of microorganisms associated with rot diseases

3.2.2.1 Sources of diseased fruits

Soursop, sweetsop and African star apple fruits showing diseases symptoms were collected randomly from the different retail points in the Greater Accra region. A total of 75 diseased fruit samples; 20 each of soursop, sweetsop and African star apple, from markets (Madina, Ashaiman and Agbogbloshie) and 15 (five each of soursop, sweetsop and African star apple) from grocery shops were collected. The fruits were wrapped in paper bags, arranged in boxes to avoid cross contamination and transported to the Plant Pathology laboratory Department of Crop Science, University of Ghana, Legon for isolation of fungi associated with the fruit rot.

3.2.2.2 Sterilization of glassware and materials

All glassware needed for the experiment including Petri dishes were washed with soap and bleach (5%), rinsed with sterile distilled water and air dried. They were heat sterilized in an oven at 175ºC for 90 minutes. To prevent fungal contaminations, the inoculation chamber was sprayed with 3% thymol whiles 70% ethanol was used to clean and disinfect workbenches before and after use. Test

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tubes and conical flasks containing media to be used and various samples were also flamed at the openings ends before and after transfers.

3.2.2.3 Preparation of water agar (WA) and potato dextrose agar (PDA)

Agar powder (Oxoid) (15 g) was weighed and dissolved in 500 ml of distilled water to prepare 500 ml of water agar (WA) in one liter conical flask and shaken to mix contents. The mouth of the conical flask was then plugged with non-absorbent cotton and covered with aluminum foil to prevent condensation on the cotton wool. It was then autoclaved for 15 minutes at 1.05 kg/cm^2 and 121°C. The mouth of the conical flask was flamed after autoclaving and about 10 ml water agar was poured into nine-centimeter petri dishes and allowed to solidify in the laminar flow chamber.

PDA powder (19.5 g) was weighed and dissolved in 500 ml distilled water to prepare 500 ml of PDA in a one-liter conical flask. The mouth of the conical flask was covered with cotton wool and aluminum foil and shaken to mix contents. It was then autoclaved at 1.05 kg/cm^2 and 121°C for 15 minutes. The PDA was poured into Petri dishes (9 cm) when cooled to 50 °C and allowed to solidify.

3.2.2.4 Isolation and identification of fungi associated with diseased fruits

A total of 75 diseased fruit samples 20 each of soursop, Sweetsop and African star apple, from markets (Madina, Ashaiman and Agbogbloshie) and 15 (5 each of soursop, sweetsop and African star apple) from grocery shops were used in the study. Isolation of fungi was done first on WA and sub-cultured onto PDA.

Tissue segments from the advancing margins of the rots in, soursop, sweetsop and African star apple were removed with sterilized scalpel, surface sterilized by immersion in 5% sodium hypochlorite for four minutes, blotted dry with paper towel and plated on WA in plates (four pieces

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per plate). The plates were enclosed in clean polythene bags and incubated under ambient conditions in the laboratory (23-30 °C in the laboratory under a 12 h photoperiod) for three days and subcultured on PDA for seven days. Frequent re-isolations were performed on PDA to preserve the purity of the strains. Pure isolates were grown in PDA, incubated at 28±2°C for six days and stored at 4 °C until needed.

Using an eight millimeter cork borer, mycelial plugs of each isolate were cut from the periphery of each culture on PDA, planted singly in the middle of plates and incubated for eight days. To aid in the identification of isolates, the nature of growth and color of the mycelium were observed and recorded. Daily colony growth diameters were measured until the mycelium filled the entire plate, and the average of mean daily growth was calculated to indicate the mycelial growth rate (millimeter per day).

For microscopic examination, slides were prepared by mounting mycelial bits in plain lactophenol or cotton blue lactophenol. The slides prepared were examined under a compound microscope at low and high powers and micrographs taken. The conidial diameters of isolates were measured, with the aid of an eye piece graticule and recorded to aid in the identification of the organisms and the average of 20 individual conidia per isolate was determined (Prihastuti *et al*., 2009). Isolates were identified to the genus level using cultural and morphological traits such as colour, growth rate, morphology of mycelial, conidia and sporulating structures as described by Valencia *et al*. (2019). Conclusive identification of fungi was based on the following culture characteristics on PDA: growth rate and colour, morphology of mycelia, conidia and sporulating structures as described by (Barnett and Hunter, 1998). For subsequent research the fungal isolates which were consistently obtained from the diseased fruit samples were preserved on slants in a refrigerator at 4°C.

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3.2.2.5 Determination of pathogenicity of fungi associated with rots in soursop, sweetsop and African star apple

Cultures of fungi (*Aspergillus niger, Colletotrichum* sp.*, Lasiodiplioda theobromae,* and *Rhizopus stonilifer,*) which were isolated from soursop, sweetsop and African star apple were plated individually and incubated for three days to obtain mycelia mats for inoculation. Healthy soursop, sweetsop and African star apples fruits free from defects such as rots, cuts and bruises were inoculated with pure culture of the isolates.

Physiologically matured soursop, sweetsop and African star apples fruits were washed under running water for 10 minutes, surface sterilized by immersion in 5% sodium hypochlorite for four minutes and rinsed three times with sterile distilled water. The fruits were then air dried at room temperature and wiped with 95% ethanol prior to inoculation. Completely randomized design with three replicates (one fruit per replicate), three replications per treatment was used. The five treatments used were cultures of *Aspergillus niger, Colletotrichum* sp.*, Lasiodiplioda theobromae,* and *Rhizopus stonilifer* that were isolated from the fruits and PDA only as control. Punctures were made on fruits with the use of a sterilized 5 mm diameter cork-borer. The punctures were filled with mycelial plugs of the test fungi from three-day old cultures for testing. The fruit plugs were replaced, and the wound sealed with parafilm tape. Control fruits were inoculated with sterile PDA only with another control set with no puncture and inoculation.

Using a completely randomized design layout, the inoculated fruits were stored at ambient conditions in the laboratory for six days with temperature ranging between 23 and 30 ^{o}C under a 12h photoperiod (light) and observed every day for disease symptoms. After seven days, the fruits were observed for symptoms of rots around the inoculated points and were cut across the points of

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inoculation to observe the internal rot symptoms. Re-isolation of rot causing fungi from inoculated fruits was done to complete Koch's postulates.

3.3 Determination of the frequency of occurrence of the isolated fungi

The frequency of isolations of fungi associated with 25 soursops, 25 sweetsops and 25 African star apple fruit rot diseases were determined by counting the number of times each fungus occurred in each fruit. Where many fungi interacted or coexisted in one diseased lesion area on the fruit, a mixed infection occurred. The number of times each fungus was encountered was recorded. The percentage frequency of occurrence was calculated using the formula as follows;

(Number of times a fungus was encountered / Total fungal isolations) × 100

3. 4 Assessment of antifungal activities of crude seed extracts of soursop, neem and pawpaw

3.4.1 Fungicide evaluated in study

Crude plant extracts of soursop, neem and pawpaw which have proven to be efficacious in other studies (Uma *et al*., 2012; Hern ́andez-Guerrero *et al.,* 2020), were tested on fungi associated with rot in soursop, sweetsop and African star apple.

The inhibitory effect of seed extracts from pawpaw, neem and soursop (with concentration 10 g/100 ml of water) and Zamir fungicide (prochloraz + tebuconazole) amended with PDA on mycelial radial growth of *Aspergillus niger*, *Colletotrichum* sp., *Lasiodiplioda theobromae,* and *Rhizopus stonolifer,* was assessed.

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3.4.2 Preparation of crude plant seed extracts

Water (aqueous) extraction using the decoction technique used to extract the crude seed extracts. The seeds of neem *(Azadirachta indica)*, soursop *(Annona muricata),* and pawpaw *(Carica papaya)* used in the study were ground into a very fine powder using a Fritsch milling machine (Frequency range 50 model) after being dried in a shed for one to two weeks. Aqueous extracts were made by adding 10 g of seed powder from each fruit individually to 100 ml of distilled water in a conical flask. After 72 h at 27 ºC in a rotary shaker, the mixture was filtered through cheesecloth and the filtrate stored in screw-capped bottles for later use (Uma *et al*., 2012).

3.4.3 Preparation of seed extract Amended Potato Dextrose Agar (APDA)

Potato Dextrose Agar (150 ml) was prepared by dissolving 5.85 g of PDA powder in 150 ml of distilled water. Three separate seed extract amended PDA at the same rate were prepared. In three separate conical flasks, 15 ml of soursop, pawpaw, and neem seed extracts were pipetted into 150 ml of cooled PDA. The extract and media were carefully swirled to ensure thorough mixture. Zamir fungicide (0.45 ml) was diluted in 150 ml of PDA to obtain the standard reference fungicide. Ten ml of each APDA was poured into sterilized 9 cm Petri dishes and allowed to set.

3.4.4 Assessment of inhibitory effect of plant seed extracts on mycelial radial growth of fungi

The assessment was carried out *in vitro* by determining the radial mycelia growth of the four identified fungi on the seed extract amended potato dextrose agar using the food poison method. Treatments evaluated in the experiment are shown in Table 1. Six millimeters of mycelia plugs were taken from five-day old actively growing cultures of the test fungi responsible for rot. One plug of each test fungus was placed in the center of plates containing each of the four APDA. A test

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fungus on an APDA constituted a treatment and each treatment was replicated five times. The control treatment consisted of a test fungus on plain PDA. The treatments were arranged in completely randomised design and incubated at 23 – 25°C and 70 – 80% RH for 14 days in the pathology laboratory of the Department of Crop Science, University of Ghana, Legon.

Radial mycelial growths of the test fungi were determined daily by measuring the diameter of the colonies from the reversed side of the petri dishes with a 30-cm ruler, starting from the first day until the fungal growth in the control had covered the entire plate. The percentage inhibition of the mycelial growth of the fungus (PIRG) was calculated using the formula below;

PIRG (%) = $\frac{R1 - R2}{R1} \times 100\%$, (Korsten *et al.,* 1995).

Where R1 = Radius of isolated fungi in control.

R2 = Radius of isolated fungi in treatment culture

Table 1: Treatments evaluated for their inhibitory effect against mycelial growth of the test fungi

Fungicide	Active ingredient	Rate of application/150 ml PDA
Neem seed extract (10 g/100 ml of water)	Azadirachtin	15 ml
Pawpaw seed extract (10 g/100 ml of water)	Flavonoids, alkaloids, tannins, steroids, and saponins.	15 ml
Soursop seed extract (10g/100 ml of water)	Annonacin and Squamocin	15 ml
Zamir 40 EW	Prochloraz + Tebuconazole	0.45 ml
Control	PDA	Unamended PDA

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3.4.5 Data analysis

Data were analyzed using ANOVA which was accomplished using GenStat version 12. Where there were significant differences Tukey's HSD test (5%) was used to separate means.

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CHAPTER FOUR

4.0 RESULTS

4.1 Knowledge, perception and experience of farmers and retailers of soursop, sweetsop and African star apple on harvest and postharvest losses and their causal factors.

4.1.1 Experience on agronomic practices

4.1.1.1 Years of experience in farming and retailing

Not less than 18 (90%) of the farmers and retailers 70 (77.8%) had been in the production and retailing business for 6 years and above (Table 2). No farmer had less than a year experience however, few retailers 3 (3.3%) had been in the business for less than a year. Most of the farmers and retailers had other sources of income in addition to the production and marketing of Soursop, Sweetsop and African star apple.

Table 2: Experience (years) respondents have been involved in production and marketing of soursop, sweetsop and African star apple in Eastern region and Accra respectively

Experience (years)	Frequency (percentage) of respondents	
	Farmers (20)	Retailers (90)
< 1	0 (0)	3 (3.3)
1-5	2 (10)	17 (18.9)
6-10	4 (20)	31 (34.4)
11-15	6 (30)	23 (25.6)
16-20	5 (25)	12 (13.3)
>25	3 (15)	4 (4.5)

4.1.1.2 Number of soursop, sweetsop and African star apple fruit plants owned by farmers in the Eastern region

Typically, soursop, sweetsop and African star apple farms in the Eastern region were uncommon

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Fruit trees were scattered on people's farms and backyards as they served as shade crops on the fields and shades for humans. However, a soursop farm with over 200 tress was observed in Kwasidoi in the Eastern region. Majority of the other farmers 11 (55%) had between 6-15 fruit trees, 6 (30%) had from 16-25 whiles a few 2 (10) had not less than 25 fruit trees on their fields (Table 3).

Table 3: Number of soursop, sweetsop and African star apple fruit plants owned by farmers in the Eastern region

Number of fruit crops	Farmers (N=20)	Percentage (%)
< 5	1	5
6-10	4	20
11-15	7	35
16-20	3	15
21-25	3	15
>25	2	10

4.1.1.3 Source of planting materials used by soursop, sweetsop and African star apple farmers in Eastern region

Most of the farmers visited 18 (90%) obtained their planting materials (seeds) from friends and family and seeds from their own fruits (Table 4). Very few obtained planting materials from agro shops, 2 (10%) and none from Ministry of Food and Agriculture (MOFA).

Table 4: Source of planting materials for farmers in Eastern region

Source of planting material	Farmers (N=20)	Percentage (%)
MOFA	0	0
Friends/Family	14	70
Agro shops	2	10
Others (own fruit)	4	20

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4.1.1.4 Trainings received by farmers on production of the fruits

Almost all the farmers 19 (95%) did not have any form of training on the production of soursop, sweetsop and African star apple (Table 5). Only one commercial soursop farmer 1 (5%) had been trained on how to produce the fruits.

Table 5: Trainings received by the farmers with regards to the studied crops

Training received	Farmers (N = 20)	Percentage (%)
Yes	1	5
No	19	95

4.1.2 Harvest practices and estimated losses

4.1.2.1 Techniques used by farmers for checking maturity of fruits.

Fruits are normally harvested depending on how matured they are. All the farmers 20 (100%) used the hand feel and visual observation technique to determine the maturity stage of the fruits. None of the farmers used instruments for checking maturity of fruits.

4.1.2.2 Stage of maturity at which fruits are harvested by producers and their associated postharvest losses

Most of the farmers 12 (60%) prefer to harvest soursop, sweetsop and African star apple when fruits are partially ripe which results in an estimated loss of 3%, 6 (30%) harvest fruits when fully ripe with 10% loss estimate and a few 2 (10%) when green and unripe with an estimated loss of 1% (Table 6).

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Table 6: Stage of maturity at which fruits are harvested and their associated postharvest losses

Maturity of fruits at harvest	Frequency (percentage) of farmers	% loss estimate from 100 fruits
Partially ripe	12 (60)	3
Fully ripe	6 (30)	10
Green and unripe	2 (10)	1

4.1.2.3 Techniques for harvesting fruits by farmers in the Eastern region

Plucking and catching fruits was the most common technique used by farmers 20 (100%) when harvesting fruits and this results in 1% of the estimated losses, followed by pulling fruits with hooks 17 (85%) with 5% loss estimated and shaking tree 7 (35%), 15% loss estimate (Table 7). None of these farmers however practiced mechanical harvesting.

Table 7: Techniques for harvesting fruits

Harvest technique	Frequency (percentage) of farmers	% loss estimate from 100 fruits
Mechanical	0 (0)	0
Pulling fruits with hooks	17 (85)	5
Shaking tree	7 (35)	15
Plucking and catching	20 (100)	1
Others	5 (25)	3

4.1.3 Postharvest practices and estimated losses

4.1.3.1 Materials used for packaging fruits on farm before distribution.

Harvested soursop, sweetsop and African star apple fruits were mostly arranged by farmers in baskets 14 (70%) for transportation and distribution which mostly does not result in loses (0% loss estimated) (Table 8). However, 6 (30%) of the farmers packaged their produce in jute sacks and pans resulting in 7% loss.

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Table 8: Materials used for packaging fruits

Materials for packaging fruits	Frequency (percentage) of farmers	% loss estimate from 100 fruits
Basket	14 (70)	0
Jute sacs	3 (15)	5
Pans	3 (15)	2
Crates	0 (0)	0

4.1.3.2 Incidence of fruit loss incurred during production and retailing

Majority of farmers 16 (80%) had not encountered fruit losses since fruits were mostly transported right after harvest (Table 9). On the other hand, majority of the retailers 85 (94.4%) tend to incur much losses since they are responsible for handling the fruits right after harvest, through transportation to storage.

Table 9: Incidence of fruit loss incurred during production and retailing

Loss incurred	Frequency (Percentage) of respondents	
	Farmers (N = 20)	Retailers (N = 90)
Yes	4 (20)	85 (94.4)
No	16 (80)	5 (5.6)

4.1.3.3 Mode of transportation of fruits by farmers and retailers

Almost all farmers 19 (95%) and retailers 88 (97.7%) patronize any available commercial vehicle to transport their produce resulting in 10% loss estimated. Some (farmers and retailers) use buses 16 (80%) and 79 (87.7%), respectively resulting in 5% loss estimated and trucks 12 (60%) and 8 (8.9%), respectively (5% loss estimated) (Table 10). Few retailers practice head loading 15 (16.7%) and some uses wheel barrows 46 (51.1%) to transport produce to sales point which accounts for no loss of the produce. None of the respondent used animals as mode of transport.

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Table 10: Mode of transporting fruits by farmers and retailers

Mode of transportation	Frequency (Percentage) of respondents		% loss estimate from 100 fruits
	Farmers (N = 20)	Retailers (N = 90)	
Trucks	12 (60)	8 (8.9)	5
Buses	16 (80)	79 (87.7)	5
Taxis	5 (25)	50 (55.6)	0
Available commercial vehicle	19 (95)	88 (97.7)	10
Head loading	0 (0)	15 (16.7)	0
Animals	0 (0)	0 (0)	0
Others (wheel barrow)	0 (0)	46 (51.1)	0

4.1.4 Source of fresh fruits for retailing, estimated losses and pricing

4.1.4.1 Point at which retailers collect/obtain produce for sale in Accra

Most retailers 46 (51.1%) obtain their produce directly from farmer's field because prices are mostly less as compared to purchasing from wholesalers and other retailers (Table 11). However, some 32 (35.6%) purchase from wholesalers and a few 12 (13.3%) from other retailers.

Table 11: Point at which retailers obtain produce for sale in Accra

Pick up point	Frequency (percentage) of respondents (Retailers)		
	Soursop (N = 30)	Sweetsop (N = 30)	African star apple (N = 30)
Farmer field	23 (76.7)	14 (46.7)	9 (30)
Wholesale point	6 (20)	11 (36.7)	15 (50)
Retail point	1 (3.3)	5 (16.7)	6 (20)

4.1.4.2 Factors that contribute to pricing of fruits by retailers in Accra

All retailers 90 (100%) priced their produce based on the cost involved in purchasing and transporting them to the sales point (Table 12). Some 83 (92.2%) priced them based on the number of fruits lost (losses incurred). The availability and scarcity of produce also contributed to pricing

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of produce by some retailers 77 (85.6%). However, a few of them 19 (21.1%) considered the prices of other competitors in pricing their produce.

Table 12: Factors contributing to pricing of fruits by retailers in Accra

Pricing factors	Frequency (N = 90)	Percentage (%)
Losses incurred	83	92.2
Purchasing and transportation cost	90	100
Availability or scarcity of produce	77	85.6
Price of other competitors	19	21.1

4.1.5 Storage, nature of loss and estimated losses

4.1.5.1 Facility for storing fruits at retail (selected markets and grocery shops) in Accra

The produce were mostly stored in common storerooms 67 (74.4%) where all other produce were stored at the sales point with 15% loss estimate and improved structures 10 (11.1%) with 7% loss (Table 13). Some retailers stored their produce in small wooden kiosks, crates or left covered with plastics or jutes at point of sale 13 (14.4%) which also results 10% of the loss estimated. No retailer used the standard storage facility.

Table 13: Facility for storing soursop, sweetsop and African star apple fruits at retail point (selected markets and grocery shops) in Accra

Storage facility	Frequency (N = 90)	Percentage (%)	% loss estimate from 100 fruits
Common storeroom	67	74.4	15
Improved	10	11.1	7
Standard	0	0	0
Others	13	14.4	10

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4.1.5.2 Number of days fruits are stored at retail points (selected markets and grocery shops) in Accra

Majority of the retail respondents [soursop; 30 (100%), sweetsop; 30 (100%) and African star apple; 24 (80%)] stored their produce between 1-10 days at retails points during sales accounting to 15% loss of produce (Table 14). A few African star apple retailers 6 (6.7%) sold all their produce in less than a day with no storage involved (0% loss). None of them stored their produce for more than 10 days.

Table 14: Storage duration (Days) for fruits at selected retail points in Accra

Storage period (Days)	Frequency (percentage) of respondents (Retailers)			% loss estimate from 100 fruits
	Soursop (N = 30)	Sweetsop (N = 30)	African star apple (N = 30)	
< 1	0 (0)	0 (0)	6 (20)	0
1-5	17 (56.7)	12 (40)	16 (53.3)	3
6-10	13 (43.3)	18 (60)	8 (26.7)	12
>10	0 (0)	0 (0)	0 (0)	0

4.1.5.3 Nature of loss for fruits during storage at retail points (selected markets and grocery shops) in Accra

Responses from retailers indicated that the nature of loss on fruits varied depending on the type of fruit. On soursop fruits, losses were mostly indicated by rots caused by microbial infection 27 (90%), other factors such as bruises and physiological rot due to heat 18 (60%) and boring by insects 15 (50%) (Table 15). Similar to soursop, in sweetsop fruits, rot by microbial or disease infection 19 (63.3%) and others; bruises and physiological rot due to heat 20 (66.7%) caused losses on fruits. However, wilting and shrinking 26 (86.7%), rots by microbial or disease infection 25 (83.3%) and others; bruises and physiological rot due to heat 22 (73.3%) was mentioned by most African star apple retailers.

Table 15: Nature of loss on fruits during storage at selected retail points in Accra during this study

Nature of loss at storage	Frequency (percentage) of respondents (Retailers)			% loss estimate from 100 fruits
	Soursop (N = 30)	Sweet apple (N = 30)	African star apple (N = 30)	
Weight loss	0 (0)	0 (0)	11 (36.7)	5
Destruction by rodents/birds	0 (0)	2 (6.7)	0 (0)	3
Rots by microbial infection	27 (90)	19 (63.3)	25 (83.3)	15
Wilting and shrinking	4 (13.3)	0 (0)	26 (86.7)	5
Spillage	0 (0)	6 (20)	19 (63.3)	2
Boring by insects	15 (50)	1 (3.3)	24 (80)	7
Others (bruises and physiological rot due to heat)	18 (60)	20 (66.7)	22 (73.3)	10

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4.1.5.4 Value of loss (GH₵) incurred by of retailers in selected markets and grocery shops in Accra

Majority of soursop retailers 17 (90%) lost between < 50 - 100 Ghana cedis at the end of sales, and just a few lost > 200 Ghana cedis (Table 16). Similarly, most sweetsop 28 (93.3%) and African star fruit 25 (83.4%) retailers lost < 50 - 100 Ghana cedis.

Table 16: Monitory value (GH¢) of loss incurred by of retailers in selected markets and grocery shops in Accra

Value of loss (GH¢)	Frequency (percentage) of respondents (Retailers)		
	Soursop (N = 30)	Sweetsop (N = 30)	African star apple (N = 30)
< 50	17 (56.7)	21 (70)	20 (66.7)
50 -100	10 (33.3)	7 (23.3)	5 (16.7)
100-200	2 (6.7)	2 (6.7)	5 (16.7)
> 200	1 (3.3)	0 (0)	0 (0)

4.2 Symptoms of postharvest rot diseases associated with fruits and identification of the microorganisms causing the rot diseases

4.2.1 Symptoms of rot diseases on fruits

Two types of rots affecting texture and colour were observed on diseased soursop and sweetsop fruits obtained from the market for isolation of fungi (Figure 1 and 2). They are the dry and soft rot symptoms found on the epicarp/skin of the two fruits. These rots occurred at any place on the epidermis of the fruit (not on a particular place such as stem of blossom end) with colors ranging from light brown to dark-brown.

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For African star apple, the deterioration in the fruit is manifested by dry and shrunken tissue with associated fungal mycelia growth (Figure 3). The colour of diseased tissue changes from the normal pinkish colour to one with brown to dark patches and shrinks.

Figure 1: Symptoms of rots on epicarp of soursop fruits

A (Dry and dark-brown rot symptoms) and B (Soft and light-brown rot symptoms) C (combination of dry rot and soft rot symptoms)

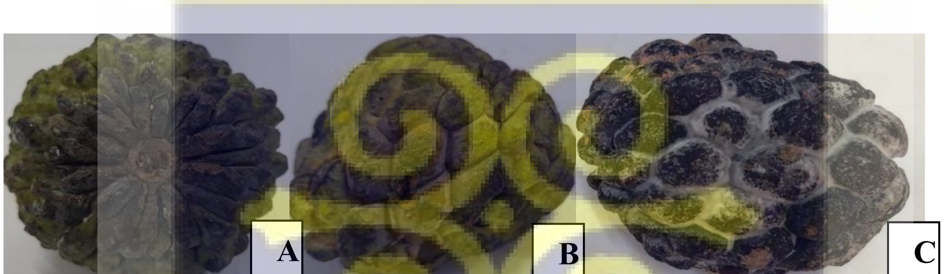

Figure 2: Symptoms of rot disease on sweetsop fruits

A (Dry and dark-brown rot symptoms), B (Soft and light-brown rot symptoms), C (Advanced soft rot with associated fungal mycelium)

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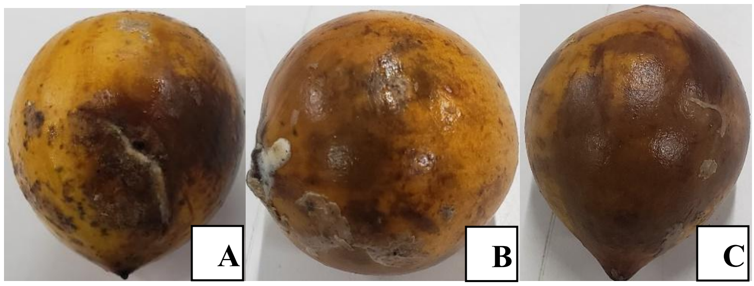

Figure 3: Symptoms of rot on African star apple fruits

A (Brown to dark patches rot symptoms), B (Brown to dark patches rot symptoms) and C (Shrinks due to rot)

4.2.2 Fungi associated with rot in/on fruits

A total of 30 fungi isolates were obtained from 25 soursop fruits, 28 from 25 sweetsop fruits and 25 from 25 African star apple fruits collected from selected markets and grocery shops in the Greater Accra region. These isolates were grouped into four based on their culture and morphological characteristics in petri dish and under microscope, respectively. The fungi were *Aspergillus niger* (soursop, sweetsop and African star apple), *Colletotrichum* sp. (soursop and sweetsop), *Lasiodipliodia theobromae* (soursop, sweetsop and African star apple) and *Rhizopus* sp. (soursop and sweetsop). The identifications were based on the following:

Aspergillus niger

Aspergillus niger obtained from soursop, sweetsop and African star apple were the first group of isolates (Fig. 4, A and B). The mycelia of the pathogen were white and creeping, and black vesicles were produced after 2 to 3 days of culture. The microscopic observation results showed that the conidial head was subsphaeroidal to radial and dark brown to deep dark brown in colour. The conidia were spherical, transparent, and colorless.

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***Colletotrichum* sp.**

The fungi showed colonies with a moderate mycelial growth rate and had dense whitish mycelium with spores which were irregular and appeared as brown to dark dots (Fig. 4, C and D). The hyphae were non-septate, cylindrical and hyaline. It had smooth hyaline and sub cylindrical conidia with rounded ends less than 4.5 μm in diameter. The spores looked like grains of rice. Development of acervuli was observed, it was disc shaped, waxy with dark or spine at the edge.

Lasiodipliodia theobromae

Colonies had fast-growing, thick, spongy, spherical, cottony mycelium that was white to grayish olive in color, had little elevation with filamentous edges. Its colony on PDA was round and smooth (Fig. 4, E and F). Initially, grey-centered white aerial filamentous mycelia formed. As the colony grew older, it became gray, then dark grey, and finally black. The pycnidia were either simple or aggregated, and they were gray in color. Conidia were elliptical to sub-ovoid in shape. They were hyaline, aseptate, and had thick walls at first, but throughout development, they developed a single medium septum and darkened, growing from 17.35 to 29.31 × 11.23 to 14.91 μm (mean 22.68 × 5.70 μm).

***Rhizopus* sp.**

It was characterized by fast, filamentous, white mycelial development. In contrast to rhizoids, sporangiophores were long, aseptate, smooth-walled, and upright. They emerged from stolons in groups of three to five (Fig. 4, G and H). A wide variety of irregular, subglobose, or ovoid sporangiospores with sizes ranging from 4 to 10×7 to 18 μm in length by width were present. The

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sporangia were spherical, pigmented, and globose. The sporangiospores were pigmented and showed an oval or round shape. Columella were 80–110 µm and mostly globose to subglobose.

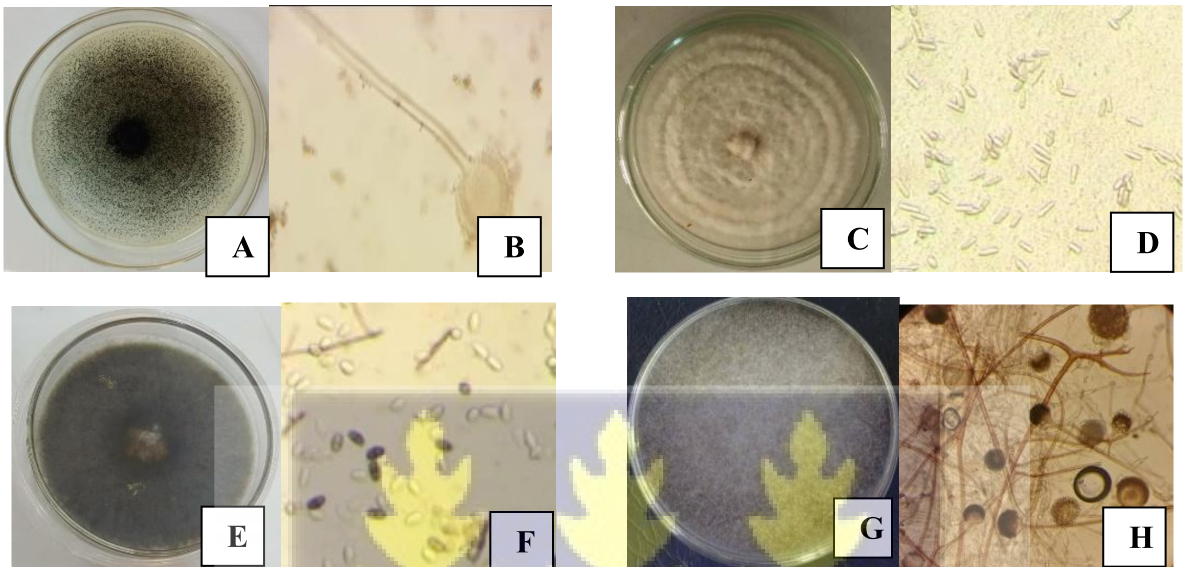

Figure 4: Cultural and morphological characteristics of isolates obtained from soursop, sweetsop and African star apple.

(A, B) *Aspergillus niger,* (C, D) *Colletotrichum* sp., (E, F) *Lasiodiplodia theobromae*, (G, H) *Rhizopus* sp.

4.2.3 Pathogenicity of fungi associated with fruit rots

All the 4 fungi genera isolated from diseased samples of soursop, sweetsop and African star apple were pathogenic for their respective fruits.

Soursop and sweetsop fruits inoculated with *Aspergillus* sp., and *Colletotrichum* sp, produced dark brown lesions, with hard dry rot after the fourth day of incubation (Fig. 5A, B, C and D) (Fig. 6A, B, C and D). The lesions in the pulp became brown with hard and dry consistency and necrotic appearance. The rot affected the fleshy part of the fruit which changed from the usual whitish colour to brown or dark brown colour.

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Soursop and sweetsop fruits inoculated with *Lasiodiplodia* sp. and *Rhizopus* sp. developed necrotic lesions and soft rot symptoms (Fig. 5E and F) (Fig.6E and F). The fruits became totally soft as days passed with light brown stains on all the pericarp. The skin became totally mummified and darkened into an intense brown colour. The whitish fleshy part of the fruits turned brown or dark brown as a result of rot.

The study also revealed that the microorganisms isolated from infected African star apple fruits (*Aspergillus niger* and *Lasiodiplodia theobromae*) were pathogenic (Fig 7A, B, C and D). The fruit was entirely disintegrated, and a black color was formed around the diseased area by the formation of mycelial tissue. The fleshy part changed from pink/orange to brown indicating rot.

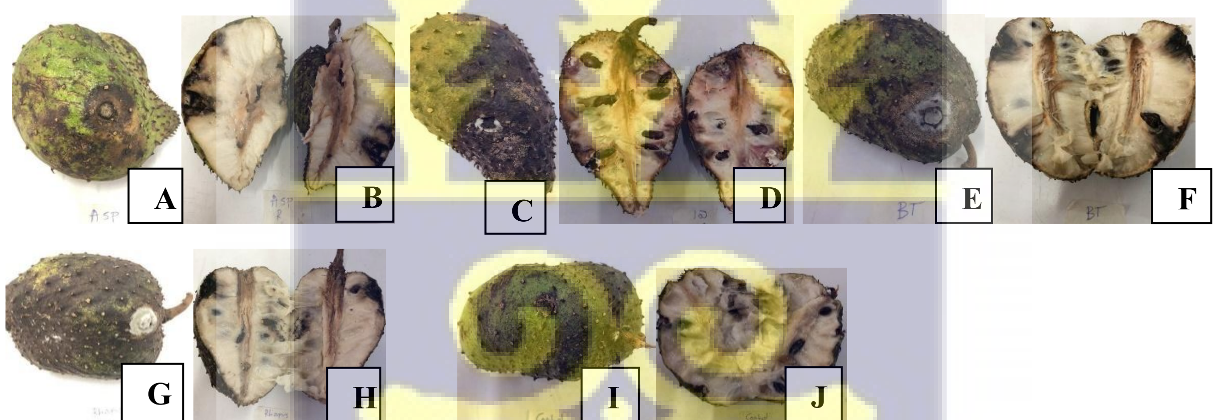

Figure 5: Symptoms of diseases on artificially induced soursop fruits

(A, B) Symptoms of rot by *Aspergillus niger,* (C, D) Symptoms of rot by *Colletotrichum* sp., (E, F) Symptoms of rot by *Lasiodiplodia theobromae*, (G, H) Symptoms of rot by *Rhizopus sp*., (I, J) Control fruits

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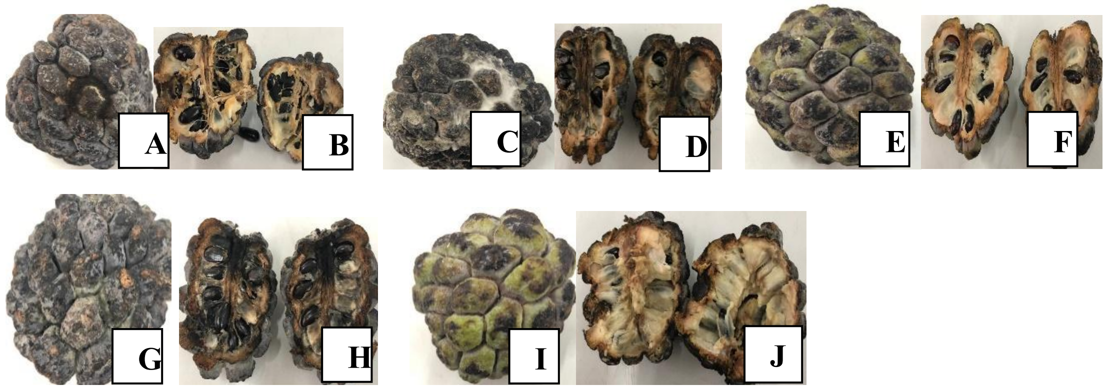

Figure 6: Symptoms of diseases on artificially induced sweetsop fruits

(A, B) Symptoms of rot by *Aspergillus niger,* (C, D) Symptoms of rot by *Colletotrichum* sp., (E, F) Symptoms of rot by *Lasiodiplodia theobromae*, (G, H) Symptoms of rot by *Rhizopus sp*., (I, J) Control fruits

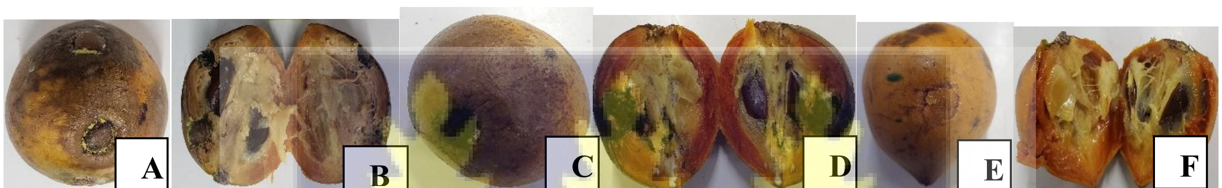

Figure 7: Symptoms of diseases on artificially induced African star apple fruits

(A, B) Symptoms of rot by *Aspergillus niger*, (C, D), Symptoms of rot by *Lasiodiplodia theobromae,* (E, F) Control fruits

4.3 Frequency of occurrence of the isolated fungi

4.3.1 Frequency and percentage of occurrence of fungi associated with fruit rot

A total of 30 fungi isolates were obtained from soursop fruits, with the highest being *Lasiodipliodia theobromae* occurring 12 times (40 %) occurrence, followed by *Colletotrichum* sp. and *Rhizopus stonolifer* occurring 7 times each (23.3 %) occurrence each, *Aspergilus niger* occurred 4 times (13.4 %) occurrence (Table 17).

Sweetsop fruit recorded 28 fungi isolates with *Lasiodipliodia theobromae* being the highest with 15 (53.6 %) occurrence, followed by *Colletotrichum* sp. 8 (28.5%) occurrence, then *Aspergilus niger* with 3 (10.7 %) occurrence and *Rhizopus stonolifer* with 2 (7.2%) occurrence.

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In all, 25 fungi were isolated from African star apple fruit with *Aspergilus niger* 14 (56 %) occurrence and *Lasiodipliodia theobromae* 11 (44 %) occurrence.

Table 17: Frequency of occurrence of fungi associated with rot in fruits

Isolated fungi pathogen	Frequency (percentage) of isolation		
	Soursop (N = 25)	**Sweetsop (N = 25)**	**African star apple (N = 25)**
Aspergilus niger	4 (13.4)	3 (10.7)	14 (56)
Colletotrichum spp	7 (23.3)	8 (28.5)	0
Lasiodipliodia theobromae	12 (40)	15 (53.6)	11 (44)
Rhizopus stonolifer	7 (23.3)	2 (7.2)	0
Total	**30 (100)**	**28 (100)**	**25 (100)**

4.4 Efficacy of seed extracts of soursop, neem and pawpaw for inhibition of mycelial radial growth of fungi responsible for fruit rot

The colony diameters of the test fungi were variably reduced by the test fungicides (Table 18). All the extracts however showed more than 70% growth inhibition on all the organisms.

From records, soursop seed extract and zamir showed the highest fungitoxic activity against *A. niger* with highly significant inhibition ($P < 0.05$) of 92% and 100%, respectively, as compared to neem seed extract (88%) and pawpaw seed extract (78%). Neem seed extract however exhibited high significant fungitoxicity than pawpaw seed extract.

Again, soursop seed extract and zamir induced highly significant reduction on radial growth of *Collectotrichum* sp. with 96% and 100% respectively. This was significantly different from neem seed extract (84%) and pawpaw seed extract (84%).

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The two fungicides exhibiting the highest fungitoxicity; soursop seed extract (96%) and Zamir (100%) significantly suppressed (P<0.05) *L.theobromae.* This was significantly different from neem seed extract (79%) and pawpaw seed extract (73%).

Generally, *Rhizopus* species was highly suppressed by all the 4 test fungicides. A highly significant reduction (P<0.05) in radial growth ranging from 100%,100%,100% and 98%, were obtained from soursop seed extract, neem seed extract, zamir (standard fungicide) and pawpaw seed extract respectively.

Table 18: Inhibitory effects of fungicides on mycelial radial growth *(Values are percentage reduction in colony diameter of fungi on test fungicides amended PDA incubated for seven days at a 23 – 25°C and 70 – 80% RH)*

Fungicides	**Test Fungi**			
	A. niger	*Collectotrichum* sp.	*L. theobromae*	*R. stonilofer*
Soursop seeds extract	92b	96b	96b	100a
Neem seeds extract	88ab	84a	79a	100a
Pawpaw seeds extract	78a	84a	73a	98a
Zamir (Prochloraz + Tebuconazol)	100b	100b	100b	100a

Means in the same column followed by the same letters are not significantly different at Tukey's HSD (P < 0.05)

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CHAPTER FIVE

5.0 DISCUSSION

5.1 Knowledge, perception and experience of farmers and retailers of soursop, sweetsop and African star apple on harvest and postharvest losses and their causal factors

The study revealed that typically, soursop, sweetsop and African star apple farms in the Eastern region were uncommon. Fruit trees were scattered on farms and backyards as they served as shade crops on the fields and shades for humans. However, a soursop farm with over 200 tress was observed in Kwasidoi in the Eastern region. Majority of the other farmers 11 (55%) had between 6-15 fruit trees. This supports a claim made by Honger *et al*. (2020) in a study that soursop fruits are not regarded as a significant export good in Ghana; as a result, the trees are handled similarly to indigenous pawpaw, mango, and avocado. The crop is only grown in backyard gardens and receives very minimal care. Nevertheless, a small number of fruits that are gathered from these trees can be found in a number of supermarkets located around the nation's cities (Honger *et al*., 2020). According to Alberto & Otanes (2016), growing soursop fruits could improve the income of those who work in their production and marketing. Fruits like African star fruits and sweetsop also stand the same change of contributing to the country's GDP and improving livelihoods of farmers and retailers. Farmers are therefore encouraged to produce these crops on a large scale

Most of the farmers 12 (60%) prefer to harvest soursop, sweetsop and African star apple when fruits are partially ripe which results in an estimated loss of 3%, 6 (30%) of them harvest fruits when fully ripe with 10% loss estimate and a few 2 (10%) when green and unripe with an estimated loss of 1%. Most of these farmers attributed the decision to harvest when fruits are partially ripe to the fact that the fruits would eventually ripen fully few days after harvest. With that farmers and retailers get enough time to sell them out because it has longer shelf life consequently leading to

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low losses as compared to fruits harvested when fully ripe. This is contrary to findings from Akurugu *et al*. (2016) where most mango farmers in the northern part of Ghana preferred to harvest their produce when fully ripe which obviously resulted in higher fruit loss. Farmers are therefore encouraged to harvest fruits when partially ripe to reduce the case of postharvest loss.

Almost all farmers 19 (95%) and retailers 88 (97.7%) patronize any available commercial vehicle to transport their produce resulting in 10% loss estimated. Some (farmers and retailers) use buses 16 (80%) and 79 (87.7%), respectively resulting in 5% loss estimated and trucks 12 (60%) and 8 (8.9%), respectively (5% loss estimated). Few retailers practice head loading 15 (16.7%) and some uses wheel barrows 46 (51.1%) to transport produce to sales point which accounts for no loss of the produce. None of the respondent used animals as mode of transport with reasons that it is outmoded. Findings from Akurugu *et al*. (2016) again confirmed the use of trucks, trunk of vehicles and Motor-king tricycles by farmers and retailers to convey mango fruits to the market or sales point. These fresh fruits are mostly transported by roads and due to the bad road networks in most parts of the country, it would be in the best interest of farmers and retailers to package their produce properly and place them securely in vehicles for transportation to reduce the rate of postharvest loss.

Upon reaching the point of sale (market and grocery shops), this survey showed that produce were mostly stored in common storerooms 67 (74.4%) where all other produce are stored at the sales point with an estimated loss of 15% and improved structures 10 (11.1%) with 7% loss. Some retailers stored their produce in small wooden kiosks, crates or left covered with plastics or jutes at point of sale 13 (14.4%) which also resulted in an estimated loss of 10%. Factors that influenced postharvest losses during storage by retailers varied with the type of fruit. Soursop fruits losses were mostly caused by rot by microbial or disease infection 27 (90%), other factors such as bruises

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and physiological decay due to heat 18 (60) and boring by insects 15 (50%) contributed to the losses. In sweetsop fruits, rot by microbial or disease infection 19 (63.3%) and others; bruises and physiological decay due to heat 20 (66.7%) caused losses on fruits. However, wilting and shrinking 26 (86.7%), rots by microbial or disease infection 25 (83.3%) and others; bruises and physiological decay due to heat 22 (73.3%) was mentioned by most African star apple retailers.

Storage in common cold rooms facilitates cross infestation from other produce since different kinds of produce are kept in the room. Storage in small wooden kiosks or boxes cannot be considered entirely safe due to the limitation of air (causing physiological rot due to heat) and exposure to rodents. Contrary to this, Benson *et al*. (2024) reported that the traditional wooden structure is the most popular method for storing soursop because it permits adequate aeration for stored soursop which could reduce storage temperature and slow down the rate at which the fruit ripens and softens. Leaving produce outside covered with just plastic or jutes at point of sales also exposes the fruits to extreme weather conditions being it sunlight or rain which eventually causes deterioration of the fruits. These findings align with a work done by Kyei & Matsui (2019), while assessing fruit perceptions of farmers on post-harvest losses in the Ashanti Region of Ghana. Kyei & Matsui (2019) revealed that factors such as loss at storage, loss by pest infestation at market centers, loss during transportation and packaging are major problems faced by people in the mango, banana and orange business although they affect them at different rates. Farmers should therefore invest in improved storage structures such as cold rooms to help extent the shelf life of the fruits, avoid harsh weather condition and rodents and reduce the rate of rot in fruits.

INTEGRI PROCEDAMUS

In evaluating critical causal factors for post-harvest losses in the fruit and vegetables supply chain in India using the Decision Making Trial and Evaluation Laboratory (DEMATEL) approach, Gardas *et al.* (2018) highlighted that the most critical factors that should be addressed to ensure

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progressive post-harvest loss reduction are: inadequate packaging facilities, inadequate storage facilities, insufficient infrastructure, improper handling of the produce at the farm and marketplace, inadequate processing facilities, lack of linkage between the farmers and processing units, lack of linkages in the marketing channel, and large number of intermediaries. A review conducted by Hailu & Derbew (2015) on the extent, causes and reduction strategies of postharvest losses of fresh fruits and vegetables revealed that fresh fruits and vegetables, are frequently lost in postharvest supply networks in both developed and developing nations. A quick fix is therefore needed to ensure a steady supply of fresh produce in both quantity and quality. Intensive and/or extensive farming, along with appropriate postharvest management of the food products produced, can compensate for losses (Hailu & Derbew, 2015). Environmental factors influence the incidence and infestation of pest (insects, rodents, and pathogens) (Hailu & Derbew, 2015) The right varieties should be chosen, harvesting and processing should be done correctly, temperature and humidity should be controlled as efficient ways to reduce post-harvest losses (Hailu & Derbew 2015).

5.2 Symptoms of postharvest rot diseases associated with fruits and identification of microorganisms causing the rot diseases

Generally, fungi plant diseases affect virtually all crops of economic importance and if not adequately managed causes significant economic damage. It was observed from this study that the pathogens caused a dry and soft rot symptoms that were found on the skin of the fruits (soursop and sweetsop). Similar to related studies, these rots appeared at any place of the epidermis of the fruit with colors ranging from between brown to dark brown (Cambero-Ayón, *et al.,* 2019). For African star apple, the deterioration in the fruit is manifested by dry and shrunken tissue with associated fungal mycelia growth. The colour of diseased tissue changed from the normal pinkish colour to one with brown to dark patches and shrinks.

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A total of 30 isolates were obtained from soursop fruits, 28 from sweet apple fruits and 25 from African star apple fruits collected from selected markets and grocery shops in the Greater Accra region. Out of that, two of the isolates (*A. niger* and *L. theobromae)* were identified in all the three fruits. However, *Colletotrichum* spp. and *Rhizopus sp*. were obtained from soursop and sweetsop fruits only.

According to González-Ruíz, *et al.* (2021) postharvest diseases of fresh produce impact negatively on yield and quality of the soursop fruit which eventually causes significant economic losses. Numerous fungi from the genera *Rhizopus, Lasiodiplodia, Gliocladium, Colletotrichum*, and *Fusarium*. were isolated and identified morphologically (González-Ruíz *et al.*, 2021). Furthermore, *Lasiodiplodia theobromae, Lasiodiplodia pseudotheobromae,* and *Nectria haematococca* were shown to be the most common pathogen species, causing postharvest diseases that affect the quality of soursop fruit. Notwithstanding, González-Ruíz, *et al.* (2021) showed that, based on bioinformatics sequence analysis of the ITS1-5.8S-ITS2 region of the rDNA of the pathogenic species found, *Lasiodiplodia* caused the most postharvest damage to soursop. Results from Cambero-Ayón, *et al.* (2019) also showed that *C. gloeosporioides* and *L. pseudotheobromae* were identified as the main cause of dry and soft rot in soursop fruits. Studies by Honger *et al.* (2020) confirmed the presence of *Lasiodiplodia theobromae* and *Colletotrichum* sp. on soursop in Ghana.

Various Studies also show fungi associated with the deterioration of sweetsop fruit. Zakari *et al.* (2018) identified *A. niger, Poma herbarum* and *R. stolonifera* on sweetsop fruits. Shamsi & Hosen (2016) also studied *Annona squamosa* showing fruit rot symptom and revealed four fungal species associated with fruit rot as *A. alternata, C. orbiculare*, *Fusarium* sp. and *L. theobromae.*

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Chukunda *et al*. (2021) showed in their study that the micro-organism isolated and identified from the African star fruits obtained from different locations in Nigeria were*: R. stolonifer*, *A. niger* and *Pseudomonas aeruginosa*. Arotupin *et al*. (2016), however, showed that the pathogenic fungi species associated with the African star fruits investigated were *A. flavus, A. fumigatus*, *A. niger*, *A. repens*, *Fusarium* sp., *Mucor mucedo*, *Trichoderma viride* and *R. stolonifer*. The results from Amusa *et al.* (2013) also showed that, eight fungal isolates were found associated with the deteriorating the African star fruits: *L. theobromae*, *R. stolonifer, A. niger, A. tamarii, A. flavus, Fusarium* spp., *Penicilium* spp and *Trichoderma* spp. All the fungal isolates were pathogenic on star apple fruits with the exception of *Trichoderma* spp. (Amusa *et al*., 2013).

All these confirms the outcome of this study therefore farmers, retailers and researchers should pay attention to these key organisms to assist in evaluating the best control for rots in the soursop, sweetsop and African star apple fruits.

5.3 Frequency of occurrence of fungi associated with the fruit rot

This study recorded 30 fungi isolates from soursop fruits, with the highest being *Lasiodipliodia theobromae* 12 (40%) occurrence, followed by *Colletotrichum* spp. and *Rhizopus stonolifer* 7 (23.3%) occurrence each and *Aspergilus niger* 4 (13.4%) occurrence. A study by Amusa *et al.* (2003) showed, a 100% rate of occurrence of *Lasiodipliodia theobromae,* which was the highest amongst *Fusarium* sp. (34%), *R. stonolifer* (8%) *and Aspergilus niger* (22%). This confirms the results of this study with *Lasiodipliodia theobromae* recording the highest frequency of occurrence in soursop.

Sweetsop fruit recorded 28 fungi isolates with *Lasiodipliodia theobromae* 15 (53.6%) occurrence being the highest, followed by *Colletotrichum* spp. 8 (28.5%) occurrence, then *Aspergilus niger* 3

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(10.7%) occurrence and *Rhizopus stonolifer* 2 (7.2%) occurrence. Shamsi & Hosen (2016) investigated *Annona squamosa* exhibiting symptoms of fruit rot and identified four fungal species *A. alternata, C. orbiculare*, *Fusarium* sp., and *Lasiodipliodia theobromae* that are linked to fruit rot. *Lasiodipliodia theobromae* had the greatest frequency (34) among the four fungal species, whereas *A. alternata* had the lowest frequency percentage of association (10).

In all, 25 fungi were isolated from African star apple fruit with *Aspergilus niger* 14 (56%) occurrence and *Lasiodipliodia theobromae* 11 (44%) occurrence in this study. Research also showed that frequency of occurrence of 69.6% for *Aspergilus niger* and 30.4% *Fusarium solani* in African star fruits (Ilondu & Bonsah, 2015) which is consistent with the results in this study which also had *Aspergilus niger* with the highest rate of occurrence.

5.4 Efficacy of seed extracts of soursop, neem and pawpaw for inhibition of mycelial radial growth

The most widely utilized method for managing fungal diseases is the use of chemical fungicides (Uma *et al.*, 2012; Shuping, & Eloff, 2017; Nabila & Soufiyan, 2019). However, synthetic fungicides have demonstrated negative effects on the environment and consumers of treated plant produce. The use of plant extracts, which have been documented to be effective in both in vitro and in vivo studies on selected fruits and vegetables against pathogens, can be an alternate approach (Gholamnezhad 2019; Nabila & Soufiyan, 2019; Zakawa *et al.* 2019; Hernández-Guerrero *et al.,* 2020).

Hernández-Guerrero *et al.* (2020) reported that aqueous extracts of papaya and soursop leaf and seed extracts against *C. fructicola* and *Nectria haematococca* showed a higher percentage of inhibition of both pathogens, however, the aqueous extract of papaya leaf was the most effective exhibiting a percentage of inhibition of 49.86% for *C. fructicola* and 47.89% *for N. haematococca*.

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Notwithstanding, Gholamnezhad (2019) demonstrated that neem seed extract was effective in controlling *Botrytis cinerea* which caused post-harvest losses in apple. It inhibited spore germination with inhibitory rates of 17.41% and 20.83% for methanolic and aqueous extracts respectively with significant difference compared to control (73.6 and 85.33%) (Gholamnezhad, 2019). Gholamnezhad (2019) also showed that, under storage conditions, the application of aqueous extract of neem (at concentration of 25%) resulted in 89.11% reduction of disease severity compared with the untreated control. Zakawa *et al.* (2019) also revealed that neem crude/aqueous leaf extract was effective against post-harvest fungal rot pathogens (*R. stolonifer* and *A. niger*) of the tomato fruit (*in vivo*). The results revealed that, there was significant difference when the neem treatment was compared with the control (Zakawa *et al.,* 2019). Moreover, treatments with 60% crude extracts of *A. indica* gave the best results on *R. stolonifer* (Zakawa *et al.,* 2019). Li *et al.* (2019) reported that *A niger* and *Botryosphaeria dothidea* that caused dry and soft rot in Pomegranate (*Punica granatum* L.), were significantly inhibited by aqueous garlic extract.

This corroborates the findings from this study that although the identified pathogens showed levels of pathogenicity, all the botanicals used in this experiment showed different levels of efficacy on the different fungi associated with rots in soursop, sweetsop and African star apple fruits. Results from this study revealed that, all the seed extracts resulted in more than 70% growth inhibition on all the organisms. Moreover, PDA amended with soursop extract showed a high efficacy with more than 90% growth inhibition on all the test fungi, followed by neem seed extract then pawpaw seed extract. There was no difference in the percentage growth inhibition rate of soursop seed extract and Zamir (the standard control). Since the potential control of fruit rot diseased by seed extracts of the various plants was done *in-vitro*, more plant extracts could be screened for their efficacies as well. Those that show high efficacy in the laboratory can be assayed on the field.

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Researchers should therefore intensity research on antifungal properties of botanicals since this study confirms the efficacy of botanicals in controlling fungi responsible for fruit rots. Farmers and retailers should consider the use of botanicals for control of rots on fruits both on the field and in the market due to its environmental friendliness and safety to human health as compared to synthetic fungicides.

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CHAPTER SIX

6.0 CONCLUSIONS AND RECOMMENDATION

6.1 Conclusions

- Farmers had little knowledge on the postharvest loss of soursop, sweetsop and African star apple fruits and their causal factors as compared to retailers who had fair knowledge since, they mostly encounter these losses. The losses were mainly attributed to microbial fruit rot amongst other factors such as physiological rot due to heat and bruises and wilting and shrinking. Majority of traders however lacked the knowledge and skill to control these rots.
- Two types on rots (dry and wet) were observed on soursop and sweetsop fruits with colours ranging from light brown-dark brown at any place on the epidermis of the fruit. *Lasiodipliodia theobromae, Colletotrichum* spp., *Aspergilus niger* and *Rhizopus stonolifer* were responsible for rot in soursop and sweetsop fruits. Rots on African star apple fruits showed dry and shrunken tissues with the colour of diseased tissue changing from normal pinkish colour to brown then dark patches. *Lasiodipliodia theobromae* and *Aspergilus niger* were identified as causal agent of rot in African star apple fruits.
- *Lasiodipliodia theobromae* had the highest frequency of occurrence, followed by *Colletotrichum* sp. and *Rhizopus stonolifer* and *Aspergilus niger* in soursop fruits. For sweetsop *Lasiodipliodia theobromae* again recorded the highest frequency of occurrence, followed by *Colletotrichum spp.*, then *Aspergilus niger* and *Rhizopus stonolifer*. From African star apple fruits, *Aspergilus niger* and *Lasiodipliodia theobromae were* recorded with *Aspergilus niger* having the highest frequency of occurrence.

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- Soursop seed extract showed the highest efficacy (*in - vitro*) with more than 90% growth inhibition on all the test fungi, followed by neem seed extract with averagely 87.75% then pawpaw seed extract (83.25%).

6.2 Recommendation

- The associations between the knowledge, perception and experience of farmers and retailers on causes of fruit rots and demographic characteristics of respondents should be studied so that the outcomes can enable extension agents target their advice to particular demographic groups.
- Farmers and retailers of soursop, sweetsop and African star apple fruits should be sensitized on the significant effects of postharvest loss especially rots by microbial infection on their business and the need to control them.
- Fungi pathogens responsible for rots in soursop, sweetsop and African star apple were identified, further studies can be conducted to determine if there are other fungi and bacteria involved in causing rots in the fruits by use of other growth media such as nutrient agar etc.
- Other fungicides which have proved efficacious for control of *Lasiodipliodia theobromae* should be tested for control of the fruit rots since it had the highest frequency of occurrence on diseased fruits.
- The method for controlling the fungi responsible for rot on the fruits in this study was done in the laboratory (*in-vitro*), further studies should be carried out in the fields (*in-vivo*) to confirm the efficacy of the plant-based extracts used.

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- The active ingredients in the soursop seed extract (Annonacin and Squamocin) which proved highly efficacious should be isolated and concentrated for further control on the field.

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APPENDIX

Questionnaire on the knowledge, perception and experience of farmers and retailers of soursop, sweetsop and African star apple on harvest and postharvest losses and their causal factors.

QUESTIONNAIRE TO FARMERS

A. Experience in agronomic practices

1. What other fruit crops do you produce aside Soursop, sweetsop and/or African star apple?

……………………………………………………………………………………………………

2. What is the size of your farm (acreage/number of trees owned) ....

3. How long have you been in the fruit production business? ....years

4. Why do you produce these indigenous crops?

……………………………………………………………………………………………………

5. How do you obtain your planting materials?

a) MOFA b) Friends c) Family d) Agro Shops e) Others…………………..

6. What influences your choice of planting material?

a) Less costly b) Readily available c) less postharvest damage d) others………………………

7. What are some of the challenges you encounter when producing these crops?

……………………………………………………………………………………………………….

8. Have you had any form of training concerning the production of these crops?

Yes ( ) or No ( )

9. If yes, what was the training about and which institution facilitated it?

……………………………………………………………………………………………………

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B. Harvest practices and estimated losses

10. When do you normally harvest your soursop/ sweetsop/ African star apple (months)?

a) 2-3 months b) 3-4months c) 4-5month d) if different please specify............................

11. What is your maturity checking technique?

a) Uses an instrument to measure b) By hand feel c) By visual observation d) others…………

12. Do you harvest when fruits are?

a) Partially ripe b) Fully ripe c) Green and unripe d) others……………………………

13. What method do you use in harvesting the fruits?

Harvesting Methods	Tick as appropriate	% loss estimate
Mechanical		
Pulling fruits with hooks		
Shaking of tree		
Plucking and catching		
Other (specify)		

C. Postharvest practices and estimated losses

14. How do you sort your fruits on the field after harvest?

a) Size b) Weight c) Colour d) Shape e) Physical blemishes

15. How do your package your fruits before distribution?

a) In basket b) In Jute Sacs c) In Pans d) Crates e) others

16. How long are fruits kept before distribution?

Point	**Period (Days)**	**Estimated loss (%)**
On farm		
Heaping before transportation		
During transportation		
Heaping at the market centre		
Others (specify)		

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17. What is the mode of transportation of fruit from the farm to the market?

Mode	Number of days to offload	Estimated loss (%)
Trucks		
Buses		
Taxis		
Head loading		
Animals		
Wheel barrow		
Others (specify)		

18. What measures do you put in place to prevent injuries on your fruits?

………………………………………………………………………………………………….

……………………………………………………………………………………………………

……………………………………………………………………………………………………..

19. How do you market your harvested fruits?

Outlet	Value (GH¢) per fruit	Estimated loss (%)
Wholesalers		
Retailers		
Processors		
Home /GIFTS		

D. Knowledge on pest and diseases

20. Do pest and disease affect your produce?

a) Yes b) No

21. Name some of these pest and diseases or describe them

……………………………………………………………………………………………………..

……

22. Can you mention some causes of infections of the fruits?

……

……

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QUESTIONNAIRES TO RETAILERS

E. Source of fresh fruits for retailing and estimated losses

23. How long have you been in the fruit retail business?

………………………………………………………………………………years?

24. What type of trader are you?

a) Wholesaler b) retailer c) assembler d) other (specify)………………………...

25. Which towns or communities do you get your produce from?

…………………………………………………………………………………………

26. At what point do you pick your fruits?

a) Purchase from farmer b) Purchase from wholesaler c) Purchase from retailer d) Specify……..

27. Do you incur losses during purchase and right after purchase of fruit? a) Yes b) No

28. If yes, describe the specific losses you incur

Stages of Handling	Nature of loss (see code below)	Quantity of produce harvested (weight)	Loss Estimated (Quantity)	Value of loss (GH)
Collecting, Selection, packaging etc at the pickup point				
Transport to home				
Sorting and Grading activities at point of sale				

1=Weight loss 2=Presence of insects 3=Destruction by rodents/birds 4=Rotting of fruits 5=Wilting and shrinking 6= Microbial or disease infections 7=Spillage 8=Boring by insects 9=Others (specify)

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29. What contributes to the pricing of your produce?

a) Losses incurred b) purchasing and transportation cost c) Availability or scarcity of the product d) Price of other competitors e) Other (specify)……………………………………………….

30. Do you get easy access to the market after obtaining your fruits?

a) Yes b) No

31. What is your mode of transportation from the purchase point to the sales point?

a) Rented vehicle b) Owned vehicle c) Any available passing commercial vehicle d) Animals

f) Other………………………………

32. Do you incur losses during transportation?

a) Yes b) No

33. Describe the losses you incur at these stages of the post-harvest chain.

Stages of Handling	Nature of loss (see code below)	Quantity of produce harvested (weight)	Estimated loss (Quantity)	Value of loss (GH)
Loading and off-loading into vehicles				
Transportation to Market				
Wholesale ends				
Retail points				

1=Weight loss 2=Presence of insects 3=Destruction by rodents/birds 4=Rot by microbial or disease infections 5=Wilting and shrinking 6=Spillage 7=Boring by insects 8=Others (specify)

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F. Storage, nature of loss and estimated losses

34. Where and how do you store your produce at retail points?

……………………………………………………………………………………………

……………………………………………………………………………………………

35. What type of facilities do you store your fruits in?

a) Improved storage facility   b) Common storeroom c) Standard storage facility

d) Other (specify)..

36. Do you store your produce for long?

a) Yes   b) No

37. How fast does the produce sell? Please state

……………………………………………………………………………………………

38. Do you incur losses when storing fruits?

a) Yes   b) No

39. If yes, describe the types, quantity and value of losses you incur during storage at market.

Storage location	Nature of loss (see code below)	Quantity of produce harvested (weight)	Estimated losses (Quantity)	Value of Loss (GH¢)
Storage at market Or Sale point				

1=Weight loss 2=Presence of insects 3=Destruction by rodents/birds 4=Rot by microbial or disease infection 5=Wilting and shrinking 6=Spillage 7=Boring by insects 8=Others (specify)