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PHYSIOLOGICAL AND PHYSICOCHEMICAL CHANGES DURING RIPENING OF TOMATO FRUIT (ASSILA) UNDER GREENHOUSE AND AMBIENT TEMPERATURE

Thesis Submitted as a Partial Fulfillment of the Requirement for the Award of Master of Science Degree in Food Science and Technology

BY

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DECLARATION

I, Labaran Alhassan Adamu hereby declare that this work herein submitted, as dissertation is the results of my own investigation. References made therein are however respectively acknowledged.

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DEDICATION

This work is dedicated to my beloved parents; Alhaji Labaran and Hajia Nusiratu for their love and immense financial supports for my life.

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ABSTRACT

Ripening under greenhouse and ambient temperature are common methods used in tomato production ripening but their effects on the quality of the fruit have not been fully investigated. The study aimed to determine the physiological and physicochemical changes in Assila tomato fruits at different ripening stages (breaker, turning, pink, light red and full red) under greenhouse and ambient temperature respectively, using standard methods. Tomato seeds (Assila variety) were planted in rubber containers, the germinated seedlings were transplanted into a greenhouse facility (32°C). Tomato fruits were harvested from the greenhouse at random and transported to a well-ventilated laboratory (25.6 °C/26.4 °C) upon reaching the mature green stage. At each stage of ripening according to the colour index, tomato samples were selected, manually graded, sorted and subjected to physicochemical and physiological analysis. Moisture content among the ripening stages for greenhouse tomatoes were significant ($p < 0.05$) with a highest of 95.15% at the full red stage and lowest of 91.78% at turning stage in greenhouse tomatoes. For both ripening methods, the highest weight loss (1.33% for greenhouse and 1.58% for ambient temperature) and lowest weight loss (0.34% for greenhouse and 0.35% for ambient temperature) was observed at the breaker stage and full red stage respectively. Firmness decreased from 4.77N to 1.61N and 4.20N to 1.33N for greenhouse and ambient temperature respectively. For both ripening methods, the highest ethylene concentrations (0.808ppm for greenhouse and 0.257ppm for ambient temperature) was in tomatoes at the full red stage whiles the lowest (0.052ppm for greenhouse and 0.110ppm for ambient temperature) was in tomatoes at the pink stage. The highest pH values (4.59 for greenhouse and 4.45 for ambient temperature) were at the breaker stage while the lowest (4.21 for greenhouse and 4.11 for ambient temperature) was at the full red stage. There was an increase in TA (0.54 at breaker to 0.94 at full red) and TSS (3.53 at breaker to 4.93 at full red) for ambient temperature tomatoes but a decrease in TA in greenhouse tomatoes (0.67 at light red to 0.40 at breaker). TSS increased from 2.64 to 4.73. Generally, the different ripening methods had varying influence on the physicochemical and physiological quality of tomato.

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CHAPTER ONE

1.0 INTRODUCTION

1.1 BACKGROUND

Tomato (*Lycopersicon esculentum*) is produced in hundred and forty four (144) countries (FAOSTAT, 2004). Next to potato, tomato is considered as an important vegetable in the world (FAOSTAT, 2004). In Africa, tomatoes are widely produced and consumed in larger quantities in their fresh and processed states compared to other vegetables. In Ghana, tomato production is one of the important agricultural sectors with several varieties planted throughout this country (MoFAIR Centre, 2008). According to Ellis *et al*. (1998), majority of people sometimes regard tomatoes as an essential ingredient in their daily meal.

According to Khachik *et al*. (2002), tomato is a key supplier of minute amount of vitamin E, vitamin C, phenolics and lycopene (a carotenoid) in every day food. Several researches had concluded that tomato and its product can help prevent cardiovascular diseases and provide an effective protection against numerous type of cancers (Barber *et al*., 2002).

According to Seymour (1993), the changing of tomatoes from their matured stage to full red stage consists of a remarkable change in composition: colour, texture, aroma and flavour. Ripening was simply thought of as resulting from the action of hydrolytic enzymes and degradative processes involving senescence. According to Kader *et al*. (1978), researchers in recent times are aware that ripening depends on degradative as well as an extensive array of distinct synthetic reactions. These changes take place in major areas of the fruits cell and are highly coordinated involving all subcellular sections. The different ripening features are regulated and coordinated by plant hormone and can be modified by factors of the environment and genetics (Crookes *et al*., 1983).

Maturity stage at harvest and cultivar (cv.) are the two major factors that affect both fresh and processed tomato quality. Stages of maturity at harvest is an important factor for determining diverse postharvest qualities of tomato characteristics such as colour, firmness, pH, acidity, sugar as well as soluble solids both in fresh market and processed tomatoes. According to Gomez *et al*. (2006), firmness and colour are what consumer's value most when purchasing tomatoes and can help in determining the maturity of a fruit. Maturity of a tomato fruit is an important factor relating to quality of processed tomato products hence, to achieve quality standards, different tomato products must have different requirements for maturity (Gomez *et al*., 2006).

Generally, tomato fruit undergoes six stages of ripening based on USDA colour chart; they encompass: green mature, breaker, turning, pink, light red and full red (Suslow *et al*., 2013). Usually tomato fruits are harvested upon reaching the fourth stage (pink stage) (Wang *et al*., 2011). Gejima *et al*. (2004) reported that the feasible means of evaluating tomato ripening stages is by visually analyzing the colour on the surface of the tomato fruit since that feature strongly relates to its ripening.

According to Garcia *et al*. (2005), fruit quality of tomato and postharvest performance is affected by changes in maturity stage. They reported that, the accumulation of sugars, acids and ascorbic acids by tomatoes occur during their ripening on the vine. They added that apart from chemical compositions, texture and flavor of a fruit also plays an important role in tomatoes quality. Flavour of tomato fruit is a combination of taste, odour and mouth feel. Tomato flavour strongly depends on the balance between organic acids, free amino acids, volatile compounds and sugars (Petro *et al*., 1986). Tomato sweetness however, depends on total sugar level; a reducing sugar (glucose) and a nonreducing sugar (sucrose) which is based on the level of Titratable Acidity

(TA). Sweetness is generally masked by sourness which is associated with the level of organic acid and thus dependent upon the stage of maturity at harvest (Borji *et al*., 2012).

1.2 PROBLEM STATEMENT

Greenhouse ripening of tomato and harvesting tomato from a plant and allowing ripening under ambient temperature are the major methods of tomato ripening in Ghana. These methods involve going through the five stages of maturity based on the USDA colour chart. There is however, dearth of information on the effects of these methods of ripening on the physiological and physicochemical characteristics of the tomato fruits after ripening. Also there are no detailed information on the process of ripening of tomato fruits by ambient temperature method. Greater postharvest losses and the lack of information on the physiological and physicochemical properties of local fruits in developing countries are the main factors limiting their trading at the international level.

1.3 JUSTIFICATION

The study will provide essential data resource on the fruit by informing farmers on the importance of the tomato ripening stages to increase commercial production and proper postharvest handling of the tomato fruit. It will also educate tomato producers on how to successfully produce quality tomatoes by ambient temperature method.

1.4 MAIN OBJECTIVE

To determine the physiological and physicochemical changes in tomato fruits at the five stages of maturity (based on the USDA color chart) under greenhouse effect and when detached from the plant and allowed to ripe under ambient temperature.

1.5 SPECIFIC OBJECTIVES

1. To determine the moisture contents, weight loss, firmness and ethylene concentration of Assila tomato at the five stages of maturity when grown under greenhouse effect and ambient temperature respectively.

2. To determine the pH, titratable acidity and total soluble solids of Assila tomato at the five stages of maturity when grown under greenhouse effect and ambient temperature respectively.

CHAPTER TWO

2.0 REVIEW OF LITERATURE

2.1 TOMATO TAXONOMY AND ORIGIN

Tomato is an herbaceous, warm seasonal crop usually in the temperate region. However, in tropical region, growth may persist (Morgan and Lennard, 2000). According to Norman (1992), the crop was known to originate in the South to Central America from Ecuador to Peru. It was believed to be introduced to West Africa by the Portuguese in the 16th and 17th century and since then, it has become a very important crop used for many products of food and other recipes**.**

According to Hanson *et al*., (2001), the second most commonly grown vegetable crop in the world after potato is tomato. Elmhirst (2006) also reported that, although in tropical climates, tomato is a perennial plant, it is yearly grown in North America with Mexico being the larger producer followed by Canada. Different climates (within a few degrees of the Arctic Circle ranging from the tropics) have become suitable for tomato adaptation. Its production however, is intense in rather dry and few warm areas in spite of its broad adaptation (Turhan *et al*., 2009).

2.2 TOMATO VARIETIES IN GHANA

Several varieties of tomato are produced in Ghana. Some of these varieties may include *Rio Grande, Pectomech, Cac J, Wosowoso, Laurano 70* and *Roma VF* (MoFAIR Centre, 2008). Bolga and Ashanti have been reported by Adubofour *et al*. (2010) as tomato varieties also grown in Ghana. According to Eric *et al*. (2015), another variety which is widely grown in Ashanti and Brong Ahafo Regions of Ghana under rain-fed condition is *Power Rano* (Eric *et al*., 2015). Besides, in Ghana, the chief variety for cultivation is *Power* variety (Ellis *et al*., 1998). However,

much recommendation is given to *Pectomech* as the preferred variety by most consumers and a suitable variety for processing, thus achieving a premium price over the local varieties in the market (Robinson and Kolavalli, 2010). *Assilla* variety on the other hand is a newly introduced tomato variety in Ghana which is widely grown in the Volta region because of its longer shelf life and heavy weight.

2.3 NUTRITIONAL AND HEALTH BENEFITS OF TOMATO

The maturation and ripening of fleshy fruits contribute largely to human diets, nutrition and agricultural activity (Pelaz *et al*., 2000). According to Kalloo (1991), tomato is known for its protective effect and its highly nutritive value. Tomato contains minerals like phosphorus and iron and is a rich source of vitamin C and A. He added that tomatoes can be eaten raw or consumed in processed forms such as paste, ketch-up, chutney, sauce, juice, puree, soup, diced, etc. Similarly, tomato is a rich source of dietary fibers, several nutrients including lycopene, beta-carotene and other antioxidants that can protect cells from cancer (Hobson, 1993).

According to Dumas *et al*. (2003), tomatoes are greater source of carotenoids and lycopene with a high quenching and an oxygen-radical scavenging capacity. They reported that, lycopene is responsible for interfering with the development of cancer cells, suppressing cell proliferation and exhibiting antioxidant (vitamin C, B-carotene, phenolic compound and vitamin E) activities.

Tomato fruit is a rich source of polyphenols which form a greater class of antioxidants in soluble solids (Helyes and Pek, 2006). According to Marsic *et al.* (2011), flavonoids and carotenoids are a group of polyphenols with an important benefit of antioxidant activity; offering protection against some forms of cancers (Opiyo and Ying, 2005).

2.4 PRODUCTION OF TOMATO

According to FAO (2010), about 129 million tons of tomatoes are produced in the world and the area of cultivation of tomatoes is likely to be over 5 million hectares. The leaders in tomato production in the world are China, India, Turkey and the United States with the leading producers in Africa being Tunisia, Morocco, Egypt and Nigeria. In 2005/2006 season, tomato production in Europe totaled 10.6 million metric tons whiles in 2005 tomato production was totaled 29.9 million metric tons worldwide. The average productivity of tomato in USA is 588q/ha, in Spain 465q/ha, in Italy 466q/ha, in Greece 498q/ha and in India is 158q/ha (FAO, 2010). Important achievement in the production of tomato is possible due to the improvement of high yielding hybrids/varieties, heterosis breeding, breeding for abiotic and biotic stresses and resistance (Food and Agriculture Organization, 2010).

According to Maynard *et al*. (1997), tomatoes can be produce by field or greenhouse production methods. They reported that, tomato plants depend on the soil for water, nutrients, anchorage and physical support for field production. The extent to which the soil provides these three factors adequately depends upon the type of soil, topography, soil management and soil structure (Maynard *et al*., 1997). For optimal yields and sufficient soil management, proper tillage is crucial in tomato production. Land preparation should involve adequate tillage operations to provide the best soil structure for root development and growth and to make the soil suitable for seedling or transplant establishment (Maynard *et al*., 1997).

2.5 GREENHOUSE PRODUCTION OF TOMATOES

Due to the changes in climatic conditions, increasing population and decreasing land sizes, one of the rapidly evolving sub-sectors worldwide is the tomato sub-sector (Odame *et al*., 2008). According to Papadopoulos (1991), to ensure the achievement of various farming objectives,

adequate supply and good quality, there is the need for the development of different tomato production technologies. One such technology is growing of tomatoes in greenhouses (under soil or soilless conditions), a practice referred to as protected culture. Odame (2009) documented the corresponding costs of different types and sizes of greenhouses and the estimated tomato yields in developing countries. In Kenya for example, the national average tomato yield is 30.7 tons/ha (GoK, 2009).

According to Mutumpike (2013), greenhouse cultivation as well as other modes of controlled environmental cultivation have been evolved to create favourable micro-climates, which favour the crop production all through the year or part of the year required, and its orientation should permit shadow of the gutter across the greenhouse covered with a transparent plastic film for admitting natural light for plant growth.

Wilkerson *et al*. (2004) reported that, soil is normally not acceptable for producing plant in a container. This is because soil does not supply the water holding capacity, necessary drainages and aeration. These situations can be improved by the use of peat, bagasse, coconut fiber (Cocus), straw, sawdust, calcine clays, rice hulls and leaf molds. Soilless growing media is usually used in greenhouses for the production of tomatoes and must be adjusted to provide the suitable chemical and physical attributes required for plant development (Wilkerson *et al*., 2004).

2.5.1 Tomatoes requirements in a greenhouse

Optimal growth of tomatoes under greenhouse condition requires certain important factors such as water, carbon dioxide (CO_2), light, tolerable temperature, proper and adequate nutrients. According to Frantz (2011), to achieve rapid growth and productivity, growers potentially have to control irrigation and fertility (root environment), CO_2 supply, light and temperature (aerial

environment). OMAFRA (2010), reported that, because of the moderately sealed nature of modern greenhouses that look like controlled environments, Carbon dioxide levels can be maintained and enhanced at all times. Carbon dioxide concentration in the greenhouse sometimes varies between 400-1000ppm. However this depends on the light conditions and the season.

According to Frantz (2011), until fruiting occurs, tomato has a high requirement of water throughout the growing period. Jones (1999) reported that during the summer months, matured tomatoes use 2 to 3 liters of water daily per plant at a higher light intensity. An excess of water however, will lead to abnormal plant development and growth, deprived growth and late flowering. Frantz (2011) also stated that uneven levels of water application may lead to physiological disorders such as cracking and splitting of the fruit skin. According to Jones (1999), 18°C-26°C is the suitable optimum range in air temperature for normal tomato plant growth. Besides, depending on the stage of production such as germination, transplanting and harvesting, temperatures can be adjusted. However, lower temperature may affect the growth and absorption of minerals. For optimum development and growth, within the range of 21°C to 27°C, a diurnal variation considered necessary is at least 5°C - 60°C.

A stable diet of nutrients in the form of fertilizer is necessary to maintain a healthy and high yielding tomato production. Fertilization of tomatoes grown in greenhouse greatly helps in the development and yield of the crop (Mutumpike, 2013). In terms of vegetative growth, the most important nutrient for tomatoes is nitrogen but can be detrimental to fruit production when too much of it is used (OMAFRA, 2010). Tomato uses nitrogen in two forms: NO_3^- (nitrate) and NH_4^+ (ammonium). According to Jones (1999), application of ammonium occurs during the early stages of plant maturity with a changeover to nitrate later in the season to encourage

continued fruit yield and plant growth and to prevent blossom-end rot (BER). Phosphorus on the other hand is needed for early fruit set, root growth and continual vegetative growth. Potassium is also needed for aiding effectiveness in hardening growth and fruit quality. However, an uneven ripening may occur due to an inadequate supply. Magnesium aids in fruit quality (Jones, 1999).

2.5.2 Planting media for greenhouse tomatoes

Commercially available materials like Peat, Coccus, Vermiculite, Perlite and locally available materials like Sand, Manure and Compost can be used in different proportions to grow greenhouse crops (Mutumpike, 2013).They should however be free from Toxic elements, Pests and Diseases. According to Mutumpike (2013), in developing countries, coccus is an imported material, therefore availability is scarce due to sourcing and importation impediments involved. Soil mixes used for greenhouse production of potted plants are highly modified mixtures of soil, organic and inorganic materials generally combined to improve the water holding capacity and aeration of the potting soil (Mutumpike, 2013).

2.5.3 Profitability and economic analysis of greenhouse tomato production

According to Lukanu *et al*. (2009), the opinion that a crop would reward a producer with extra earnings which is often measured as the source for a viable business is known as profitability. Lipsey (1975) also added that profitability in economic analysis is a relative term derived from profit (total revenue minus total costs). Engindeniz (2007) also made it clear that total costs can be classified into fixed and variable costs. Variable costs are those related with production including all inputs like fertilizer, labour, seed-seedling, pesticide and transport. Engindeniz and Gül (2009) further explained that labour costs and market input prices are used to determine variable costs. Fixed costs are costs that don't vary with production and they include interest on

total variable costs, annual initial investment costs, administrative costs, land rent and interest on total initial investment costs. According to these terminologies, Bayramoglu *et al*. (2010) reported that uncertified tomato producers had lower net income per unit area compared to certified tomato producers.

Usually, with good marking and management of tomatoes, greenhouse tomato production can be of a huge sum of profit. The estimation done by LSU AG Center in 2008 indicates that 20 greenhouse tomato producers in the state for example had a total of about 130,000 square feet in production, with sales of more than $1 million at an average price per pound of $1.50 (Rogar, 2010). The USDA reports tomato wholesale and retail prices and recently has included the premium greenhouse tomato in these price reports.

2.6 FRUIT RIPENING AND GROWTH

Seymour *et al*. (1993), defines fruit ripening as a special process of a plant's development whereby mature seed bearing organ undergoes metabolic and physiological changes that stimulate seed dispersal. According to them, anatomically, a fruit is a swollen ovary that may also contain related parts of a flower. Fruit growths follow fertilization and occur simultaneously with maturation of seed. Fruit initially enlarges by increasing in cell volume through the division of cell. The embryo undergoes maturity and the seed acquires desiccation tolerance, loses water and accumulates storage products. The fruit then ripens. Seymour *et al.* (2002) also stated that ripening of fruit is an irreversible phenomenon which is genetically programmed and highly coordinated and involving a sequence of organoleptic, biochemical and physiological changes, that finally leads to the development of a soft edible ripe fruit with desired quality characteristics.

According to Seymour *et al.* (2013), during ripening, many physiological alterations occur including aroma build-up, texture softening, sugar and colour changes. Gray *et al.* (1994) reported that the change in the colour of tomato fruit results from the degradation of chlorophyll, from the accumulation of pigments such as lycopenes and carotenes, as well as from the transformation of chloroplasts into chromoplasts, which are accountable for the orange and red colour of the fruit. Seymour *et al.* (1993) also reported that the production of complex volatile compounds and the accumulation of sugars (glucose and fructose) and organic acids in vacuoles are responsible for the flavour and aroma of the fruit.

In general, ripening of fruit involves many biochemical and physiological changes in the tissues of fruit which under ideal conditions, are integrated and lead to the production of suitable ripe fruit (Thompson, 1996). Physiologically, according to Thompson (1996), fruit ripening is a stage where growth ceases followed by senescence and ultimately leading to the death of the fruit. He added that fruit ripens by a series of irreversible biochemical and physical processes. This genetically programmed irreversible process has received attention of many plant horticulturists, biochemists and physiologists. During the early stages of senescence of fruits, a series of changes occur wherein the composition and structure of the unripe fruit is transformed so that it becomes edible (Rhodes, 1980). These changes occur as a result of the complex network of catabolic and anabolic reactions occurring during fruits ripening.

2.7 CLASSIFICATION OF FRUIT RIPENING STAGES

Fruit ripening can be either climacteric (depending on ethylene production to fully ripen) or non-climacteric (independent of ethylene production to fully ripen) (Gapper *et al.*, 2013). Non-climacteric fruits such as citrus, capsicum and strawberry when harvested at the mature green stage do not ripen naturally. Also during ripening, exhibit steadily declining levels of CO_2 and

minimal ethylene production level while climacteric fruit like banana, apples and tomato are extremely sensitive to ethylene treatment and exhibit higher CO_2 and ethylene levels (Bapat *et al*., 2010).

According to Abeles *et al*. (1992), non-climacteric fruit maturity does not show increased respiration followed by ethylene burst whiles climacteric fruits are typified by an increase in production of ethylene which is accompanied by a respiratory climax of ripening called the climacteric crisis. Climacteric fruits extend a wide range of angiosperm evolution, including both monocots (banana) and dicots (tomato). However, members of the same or closely related species include both non-climacteric and climacteric varieties (Perin *et al*., 2002). According to Wilkinson *et al*. (2004), the use of tomato as a model for ripening of climacteric fruit has helped in characterizing and identifying of various ripening associated genes that affect colour, aroma and cell wall metabolism. The most widely studied system for non-climacteric ripening is strawberry.

2.8 MOLECULAR BIOLOGY OF TOMATO FRUIT RIPENING

According to Oeller *et al.* (1991), hormones are used by plants to communicate among tissues and are responsible for the coordination of reproduction, germination, environmental responses, growth and development in plants. Before ripening begins, an increase in ethylene (a cause in the process of ripening) production is observed in tomato fruit.

Generally ripening initiates in one area of the fruit and continues to spread to adjacent areas as ethylene gas assimilates the process of ripening, which diffuses from cell to cell throughout the fruit. Nevertheless, not all the ripening related events depend on ethylene; some are controlled by other factors of development or hormones (Lelièvre *et al.*, 1997). According to Alexander and

Grierson (2002), to coordinate the ripening process of a fruit, both the ethylene-independent and ethylene-dependent pathways must coexist. Ethylene remains the dominant activator for tomato fruit ripening even though suggestions have been made that both ethylene independent and ethylene dependent gene regulation pathways coexist to coordinate the process in non-climacteric and climacteric fruits (Lelievre *et al*., 1997).

According to Klee (2002), genomics tools have also been used massively in defining the molecular and biochemical bases of colour, flavour, aroma and texture and in confirming and identifying the genes involved in fruit quality. According to Seymour *et al*. (2002), the genetic-regulatory factors that influence the shelf life and texture of a tomato fruit and the important enzymes involved in fruit softening have been characterized. However, the specific action of these enzymes is not entirely understood (Brummell, 2006).

The group of cell wall proteins known as expansions, are known to be involved in tomato fruit ripening. Catala *et al*. (2000) reported that, expansin co-expresses with cellulose encoding genes and xyloglucanendotransgly-cosylase during the development of fruit (Catala *et al.,* 2000). However, most of other genes of expansin are expressed during the development of fruit (Bertin, 2005).Yet still, the role expansins play in fruit ripening remains unclear.

2.9 TOMATO RIPENING STAGES

According to Suslow *et al*. (2013), once the tomato fruit completes its development and attains final size, it is in mature green stage. The fruit then stops growing and starts ripening by sequential stage transition. Tomato ripening process sequentially passes through six stages (Figure 2.1), on the basis of the percentage of its external colour: Green matured with no external red coloration, Breaker stage – where <10% of red coloration occurs at blossom end, Turning

stage – where 10% to 30% of the surface of the fruit is with red coloration, Pink stage – where 30% to 60% of the surface of the fruit is with red coloration, Light Red stage – where 60% to 90% of the surface of the fruit is with red coloration and Full Red stage – where 90% to 95% of the surface of the fruit is with red coloration. Seymour *et al.* (2002) reported that, the climacteric rise at ethylene observed in breaker stage is the key regulator for all the changes during ripening. According to them, in developing countries, usually fruit growers pick the fruits before breaker stage and apply exogenous ethylene to the fruits to induce ripening after reaching the destination. This practice is suspected to have an impact on the physiological and physicochemical content of the ripe tomato. Figure 2.1 shows the various ripening stages of tomato.

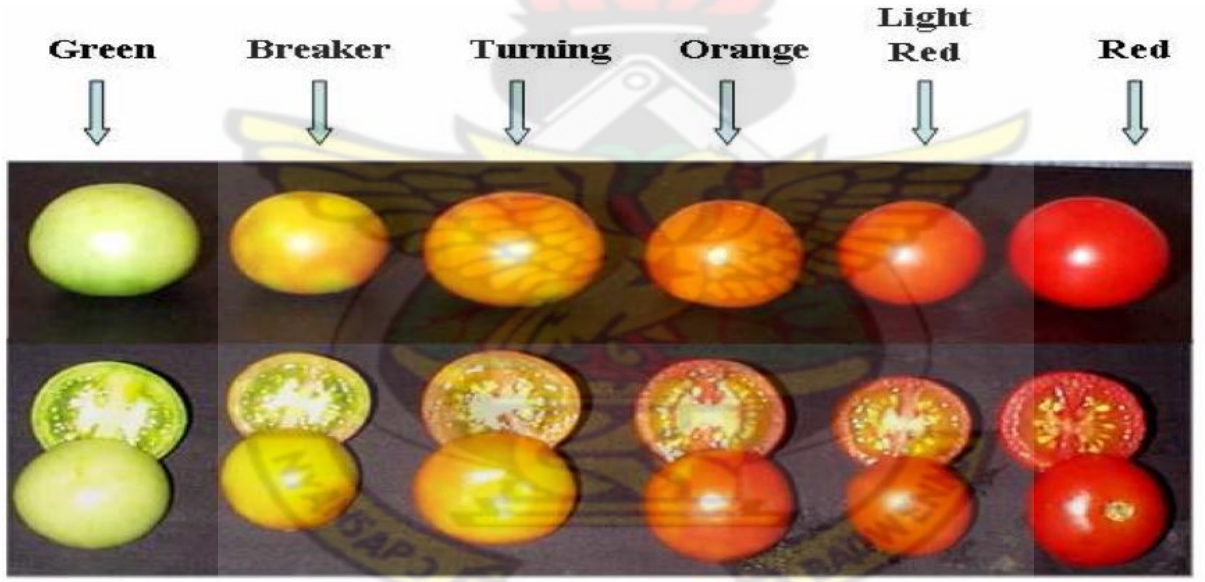

Figure 2.1: Ripening stages of tomato fruit

Source: Standard for grading of tomato (USDA, 2010).

2.10 MATURITY AND HARVESTING OF TOMATO

FAO (2010) defined maturity indices as the principles dictating at which vegetable/fruit maturity stage harvest must take place. Maturity indices of fruits depends on either their commercial or

physiological maturity. Commercial maturity deals with the changes in the fruit components during the development of the fruit. Physiological maturity on the other hand is the stage when ripening begins after growth ends (Reid, 1992). According to Kays (1991), integration of various physicochemical factors can be used for the assessment of the date of harvest. However, experienced growers based on their previous observations depend mostly on the individual assessments. For this reason, fruit maturity assessment continues to remain an unsolved problem.

According to Stanley (1998), when fruit is harvested fresh, it continues to live an independent life (does not depend on the photosynthetic activity of the leaves, conduction of vascular tissue and the absorption of minerals and water by the roots). It still undergoes metabolic reactions, using the nutrients that was accumulated during growth. An inflow and outflow of metabolites may influence the metabolism compared to most of the other tissues. Hence, fruits can be considered as an isolated system.

Salunkhe and Desai (1984) reported that harvesting of physiologically matured fruits is very important because at this stage, fruits have the ability to attain maximum storage life and to ripen on their own even when offered with suitable environmental conditions. According to FAO (1989), when a fruit or a vegetable is harvested freshly, its life processes continues in a way that the plant depends on its stored reserves, since it can no longer absorb water and food materials. Fruits and vegetables become exhausted as they undergo the process of ageing leading to deterioration and breakdown.

Tomato fruit is ready to be harvested when its surface area becomes even and its texture becomes soft. The ripening of fruit occurs from its bottom or “blossom end” to its top or “shoulders” where it is attached to its stem (Renee, 2011). Harvesting of tomato fruit at a particular stage is

very important to its quality and composition. For example tomatoes when harvested at their green mature stage usually give a flavour which is desirable at their Full Red stage when compared to those harvested at their stage of immaturity. However, tomatoes have limited storage life when harvested at its full red stage (Kader, 1986). According to Sammi and Masud (2009), harvesting of tomato at a particular ripening depends on the buyer's readiness and the location of the market. Opiyo and Ying (2005) also reported that, harvesting at certain ripening stage of tomato usually depends on the requirements of the consumers and the market as well as the length of time the tomato fruit is attached to its vine.

2.11 PHYSIOLOGICAL CHANGES DURING TOMATO RIPENING

2.11.1 Respiration rate

In terms of respiration rate, there are two types of fruits. These are climacteric and non-climacteric fruits. Climacteric fruit during ripening, shows a sudden increase and decrease in respiration rate. While for non-climacteric fruits, the sudden increase and decrease in the rate of respiration is not observed (Hurr *et al*., 2005). According to Seymour *et al*. (1993), three possible reasons for the respiration of climacteric fruits may arise. The first reason is the use of energy (in the form of ATP) to drive the elementary changes of ripening such as the synthesis of new amino acids and carotenoids. Therefore the respiratory cycle (energy processing cycle) is up-regulated and carbon dioxide becomes the by-product. Second reason is that, during the synthesis of ethylene, the energy (in the form of ATP) becomes necessary for nurturing the yang cycle and therefore the respiratory pathway generates carbon dioxide. The third reason is that, the ethylene in plant cells can go through oxidation to produce carbon dioxide. The rate of the oxidation pathway during the climacteric peak of ethylene can therefore be increased. Since the production of ethylene during the ripening of non-climacteric fruit is negligible, it is not necessary to either

induce the ethylene oxidation pathway or to sustain the level of ethylene by increasing the production of ATP, thus the level of respiration reduces.

According to Lieberman (1979), respiration is an irreversibly essential active process of metabolism of a fruit/vegetable which is associated with biochemical, physiological and histo-chemical changes. He also added that respiration is regarded as a programmed continuation of both anabolic and catabolic processes. Seymour *et al*. (1993) also reported that, the respiratory climacteric is accompanied by an increase in the production of an endogenous autocatalytic ethylene.

In recent times the purpose of increasing respiration of climacteric fruit during its ripening has become the topic with much discussion. The common opinion is that increased respiration is required to provide substrates and ATP (adenosine triphosphate) for several anabolic processes associated with ripening (Blanke, 1991). Blanke (1991) reported that the respiration of a fruit involves the oxidation of sugar (glucose) to H_2O (water) and CO_2 (carbon dioxide) and the production of energy (in the form of ATP). The process of respiration of fruits is considered an efficient system because about 90% of the energy produced is being preserved within the fruit whiles the remaining 10% is being lost as heat.

2.11.2 Ethylene Production

According to Irtwange (2006), most plant tissue produces an ethylene gas which is an important factor in the initiation process of ripening. Abeles *et al.* (1992) reported that the production of ethylene gas by fruits shortly after they are physiologically matured, initiates the metabolic pathways, induces the respiratory climacteric responsible for the changes that occur during ripening and induces a uniform ripening all over the fruit surface. According to them, the small,

freely diffusible hormone, ethylene, plays a vital role in the integration of events of development with an outside stimuli.

Many researchers have confirmed the involvement of ethylene gas in a number of stages of development and growth of a plant, such as germination of seed, ripening of fruit, growth and development of root, abscission and senescence of leaf and flower, somatic embryogenesis, inhibiting the elongation of roots and stems, expansion of leaves, formation of flowers, development of root nodules and hairs, fruit senescence, fruit abscission and ripening of fruit (Mattoo and Suttle, 1991). According to Pech *et al*. (1993), lower and higher temperature droughts/floods, attack by pathogens, heavy metals, treatments with other hormones and wounding are the different types of stress that synthesizes ethylene gas.

Analysing the internal ethylene concentration at harvest can be of importance to predicting the potential shelf life and storage of fruits and also to determine the fruit optimum harvest date (Dilley, 1980). However, the limitations of the commercial application of such technique results from the differences between fruits that is influenced by cultivar, temperature, latitude and the time of harvest (Blanpied *et al.,* 1985).

2.11.3 Colour Change

According to Seymour *et al.* (1993) colour plays an important role as a feature use for determining tomato fruit quality. Moreover, a consumer considers colour as an important attribute for indicating the quality of eating. Changes in fruits colour (from green to yellow) is mostly due to the degradation of chlorophyll. This leads to the exposure of the existence of the yellow pigments (carotenoids). However, the biosynthesis of carotenoids is highly temperature sensitive (Tomes 1993). According to Fraser *et al.* (2001), carotenoids are C40 iso-propanoid

compounds that play a part in numerous processes in plants physiology. This makes carotenoids important compounds that play a key role in photosynthesis, where they function as protectors of photo-oxidation and carriers of energy (VanDen Berg *et al.*, 2000).

The β-carotene and lycopene contents of tomato fruit are the two main factors responsible for its colour. According to Tomes (1993), during ripening at a temperature of 31°C and above, inhibition of lycopene development may occur. Boe *et al.* (1967) reported that during the development of a fruit (from mature grown to ripening stages), the concentrations of lycopene and β-carotene keeps increasing.

2.11.4 Firmness

Generally, softening is associated with fruit ripening with which results from the cell wall disruption (Manganaris *et al.*, 2007). According to Seymour *et al.* (1993), three mechanisms are responsible for the softening of fruit; protopectin degradation, the loss of turgor and the metabolism of the cell wall of fruit during riepening by enzymes such as cellulose, β-galactosidase, PG (polygalacturonase) and PME (pectin methyl esterase). The level of fruit softening is indicated by the firmness of the fruit. This is related to how susceptible tomatoes are towards being physically damaged when harvesting and thus can be influenced by the stage of maturity (Adedeji *et al*., 2006).

According to Adedeji *et al*. (2006), firmness decreases during ripening of a tomato fruit. They reported that, the degradation of polysaccharides may be the cause of the decrease in firmness of fruit during its ripening. A study by Moneruzzaman *et al*. (2008) indicated that under standard conditions, for a tomato to become soft at its green matured stage, it requires a maximum of 15 days. Half ripe tomatoes on the other hand require 12 days whiles tomatoes at full ripe stage

requires 9 days to become soft. They found that for tomatoes that are covered with straw, green matured, partially ripe and fully ripe requires 15days, 12days and 6days respectively to become soft. They observed that firmness decreases with advancement of time. Tilahun *et al*. (2013) also in their study observed that, tomato fruit firmness was influenced significantly by the stage of maturity at harvest. They observed the highest value in green matured tomatoes with the lowest value observed in full ripe tomato. They found out that, tomato fruit firmness decreases remarkably during its ripening where tomatoes at the green matured stage was more firm.

2.12 PHYSICOCHEMICAL CHANGES DURING FRUIT RIPENING

2.12.1 pH and Titratable Acidity

According to Gordon *et al*. (2011), TA (Titratable Acidity) and pH of a fruit are the two essential quality characteristics of its processing. TA is an approximation of the total acidity of a solution whiles the measurement of a solutions alkalinity or acidity is the pH (sperdirect, 2017). Development of the pH scale (from 0 to 14) was due to the temporary dissociation breakdown of water by the use of mathematical calculations. Values that are above 7 are considered alkaline while those below 7 are acidic. The pH value which is considered neutral (neither alkaline nor acidic) is 7 (foodsafetysite, 2017).

In industrial processing, the most universal of all analytical measurements is pH measurements. The measurement of pH plays a vital role in food processing since it involves the direct measurement of H^+ (acid content) of a food (foodsafetysite, 2017). Even the little change in pH is significant due to the logarithmic nature of the measurement. A pH difference between 6 and 5 signifies a tenfold increase in the concentration of acid and just a change of 0.3 will double the acid concentration (Gordon *et al*., 2011). Difference in pH can affect shelf life, consistency and flavour. Monti (1980) suggested that the optimum target pH and the maximum desirable pH for

safety must be 4.25 and 4.4 respectively. Industrial processors of tomatoes in the world usually indicate 4.3 or 4.2 pH values in their processed products (Gordon *et al*., 2011).

According to Gordon *et al*. (2011), food acidity has been used for centuries for the preservation of food, thus it plays a vital role in the preservation of fermented foods. The combination of acidity with other factors (chemical preservatives, heat and water activity) acts to prevent the spoilage and deterioration of food (Gordon *et al*., 2011). They reported that, the intensity of acidity of products such as sauerkraut, grapefruit, pickles and yogurt results in their sour taste or tartness.

Food acidity can be obtained during microbial fermentation of foods or may naturally be found in fruits like citrus, apple, strawberry and tomato. Desirable products such as buttermilk, fermented meat products and yogurt are produced by the direct addition of selected bacterial cultures which produces acid to foods (Gordon *et al*., 2011). Also acid may be directly added to foods; a typical example is adding lactic acid, citric acid as well as acetic acid to olives (Spanish type), beverages, vegetables and fish respectively. They reported that, the pH value of a food is determined by the intensity of its acidity. According to Alvarez *et al*. (2015), during storage, processing and distribution of foods, one of the key factors for determining growth and survival of microbes is their pH. As a result, processors of food are interested in preventing the spoilage and deterioration of products and in controlling microbial growth by determining and maintaining the pH of foods at particular levels.

The use of pH in food to control microbes can be achieved by the reduction of the resistance of heat of microorganisms and by direct inhibition of microbial growth. Majority of fruits do not require pressure and may be given a mild heat process with a temperature that is not above 212°F

since most fruits are naturally acidic. However, vegetables require a severe heat process to destroy all *Clostridium botulinum* spores since they are predominately low acid foods (Alvarez *et al*., 2015). To ensure the safety of a tomato fruit for example, a less drastic thermal treatment is required for the elimination of spoilage microbes, since tomato fruit is not classified as a low acid food (Gordon *et al*., 2011). Gordon *et al.* (2011) suggested that, it is necessary for the pH of acidified foods like fish, cucumber, cauliflower, artichoke, and pepper be left to thoroughly become stable (equilibrate) before the application of heat. To achieve that, provision of enough time for a drop in pH to below 4.7 is required by adding acid sufficiently and mixing properly (Gordon *et al*., 2011).

According to Alvarez *et al*. (2015), the growth of microorganisms requires certain maximum, minimum and optimum pH. However, nearly all microbes grow best around 7.0 of pH value whereas only a few grow below pH of 4.0. Molds and yeasts for example can grow at lower values of pH compared to bacteria since they can tolerate acid. Below pH values of 4.5, foods are more susceptible to spoilage by molds and yeasts but are usually not easily spoiled by bacteria (Alvarez *et al*., 2015). They reported that, the growth of microbes can occur on a wider range of pH. This range is most likely the variations between different types of food, types of growth medium, bacterial strains and the type of base or acid used for pH adjustment. According to Samina (2015), fresh fruit with pH range from 2.5 to 5.5 tends to inhibit the increasing of microbes and prolong its shelf life. Similarly for vegetables with pH values which ranges from 4.6 to 6.4.

2.12.2 Total soluble solids

Saltveit, (2005) defines fruit total soluble solids as its soluble solids concentration indicator that is mainly influenced by the fruit sugars. According to Saltveit (2005), the TSS (total soluble

solid) content of a fruit is expressed as degree brix. The percentage of a reference solution of sugar is related to total soluble solids. Fructose is the main sugar content of total soluble solids. US grading standards reported that, a minimum sugar of 8 percent must be in melon fruit. However, melon fruits composed of 10 to 12 percent sugar can be well transported and has an excellent quality of eating. Also, melon fruits with 12 to 14 percent sugar content are suitable for local market. A melon fruit is considered overripe if its sugar content is above 15 percent (Saltveit, 2005).

Helyes *et al*. (2006) reported that, changes in tomato TSS is in the range of 4 to 9 degree brix. Also in tomato fruit, its organic acid (mainly citric and malic acid) ranges from 0.3 to 0.6 percent. The combination of fruit acid and its total soluble solids is an important component of its flavour intensity, its sourness and sweetness**.** Fully ripe tomato fruit contains carbohydrates which constitute about 65 percent of its soluble solids; high acid and carbohydrate are however required for best flavor (Helyes *et al*., 2006). Besides, the aroma, flavor and taste of a fruit develop as a result of the production of complex volatiles and the accumulation of organic acids and sugars (Hurr *et al*., 2005).

According to Kumar *et al*. (1993), 4.80 to 8.80 percent total soluble solids of a tomato fruit indicate its maximum quality for processing in the industry. They reported that tomato TSS is a good parameter suitable for its quality in the manufacturing of paste in the industry. Campos *et al*. (2006) also reported that, 6.57 degree brix total soluble solid content of a fully ripe tomato fruit is considered of high quality and 4.47 degree brix total soluble solid content of a green mature tomato is considered of low quality for processing in the industry. They mentioned that better tomato product yield is associated with higher values of degree brix. The efficiency of

tomato paste is increased by the high value of total soluble solid (between 5 and 6.5 percent) in industrial tomatoes (Garcia *et al*., 2005).

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 RESEARCH DESIGN

Physicochemical and physiological qualities of tomato fruit were determined at each ripening stage under two conditions: greenhouse growth and ripening under ambient temperature as described below. Assila tomato seeds were obtain from the Department of Horticultural of Kwame Nkurmah University of Science and Technology-KNUST Kumasi Ghana.

3.1.1 Studies under greenhouse effect

Tomato seeds (Assila variety) were planted in rubber containers containing a cocus media (coconut back) at the Department of Horticultural of Kwame Nkurmah University of Science and Technology-KNUST Kumasi Ghana. After 28 days of planting, the germinated seedlings were transplanted in the morning into a greenhouse facility at the same department (Figure 3.1) and allowed to grow at an average temperature of 32°C with average relative humidity of 80%.

Fig 3.1: Greenhouse facility at the Horticultural Department (KNUST-Kumasi-Ghana)

At each stage of ripening, according to the "Standards for Grade of Fresh Tomatoes (7 CFR 51), US. Department of Agriculture, 2010", tomato samples were selected (Figure 3.2), manually graded, sorted and subjected to physicochemical and physiological analysis.

Table 3.1: Tomato fruit ripening stages in the Greenhouse after transplanting

Ripening stages of the tomato fruit	Ripening period (days)
Breaker	68
Turning	70
Pink	72
Light Red	73
Full Red	74

Fig 3.2: Harvesting of green matured tomatoes at the greenhouse

3.1.2 Studies under ambient temperature

Tomato fruits (120) were harvested from the greenhouse at random and transported to a well-ventilated laboratory (at the Department of Food Science and Technology, KNUST) upon reaching the mature green stage, 65 days after transplanting. These were allowed to "selfripen" in paper boxes with ventilation holes and at ambient temperature between 25.6 °C to 26.4 °C

with a relative humidity between 70 to 75%. At each stage of ripening (Breaker, turning, pink, light red and fully red) (Figure 3.4) according to the colour index (López *et al*., 2004), tomato samples were selected (Figure 3.3), manually graded, sorted and subjected to physicochemical and physiological analysis. Fig. 3.4 shows the different stages of ripening of Assilla.

Fig. 3.3: Green matured Assila tomato fruit obtained from the greenhouse.

BREAKER TURNING PINK LIGHT RED FULL RED

Fig. 3.4: Ripening stages of Assila tomato

Table 3.2 Tomato ripening stages at ambient temperature after transplanting

Ripening stages of the tomato fruit	Ripening period (days)
Breaker	69
Turning	72
Pink	75
Light Red	77
Full Red	79

3.2 PHYSIOLOGICAL ANALYSIS

3.2.1 Determination of moisture content

The determination of moisture content was by the method of AOAC (2005). Tomato fruit (2g) was weighed and dried in an oven at 100°C (± 2°C). The analysis was done in triplicate and the moisture content was determined using the following relationship:

$$\text{Moisture content (gm /100gm) sample} = \frac{\text{Initial weight- Final weight}}{\text{Weight of the sample}} \times 100$$

3.2.2 Measurement of weight loss

The percentage weight loss was determined as described by Javanmardi and Kubota (2006). The weight loss of the tomato fruit was recorded at each ripening stage of growth and calculated using the equation below.

$$\text{Percentage weight loss} = \frac{\text{Initial weight - Final weight}}{\text{Initial weight}} \times 100$$

3.2.3 Firmness

A penetrometer (*FT 327, Effegi, Italy)* was used to measure the firmness of the tomato fruits and the values were expressed in Newton. The required force using a standard probe, to make a pre-determined pierce was measured. The force recorded as the standard probe penetrates the tomato fruit to a pre-determined depth was noted as the firmness of the tomato (Kumah *et al*., 2011).

3.2.4 Ethylene concentration

Tomato fruit ethylene concentration was measured using an ethylene analyzer (F-900 Portable Ethylene Analyzer). The tomato fruit was placed in a 5L gas jar of the ethylene analyzer. The ethylene concentration was obtained from direct reading on the analyzer as described by Warton *et al*. (2000).

3.3 PHYSICOCHEMICAL ANALYSIS

3.3.1 pH determination

A micro-computer pH meter (pH vision-model 6071-Taiwan) was used to measure the pH of the tomato fruits. The pH meter was standardized using pH 4.0, 7.0 and 9.2 buffer solutions. Tomato juice was extracted by chopping the tomato fruits in smaller pieces which was mashed and blended for 10 minutes using an electric blender (Blender model BLG-555-China). After extraction, 10mL of the extracted juice was transferred into 50mL beaker. The pH of the extracted juice was then measured for each ripening stage (Tilahun *et al*., 2013).

3.3.2 Titratable Acidity (TA)

The Titratable acidity was determined as described by Mohammadi-Aylar *et al.* (2010). After extraction, 50mL of distilled water was added to 6mL of the extracted tomato juice. Using phenolphthalein indicator, the titratable acidity of tomato juice was obtained by titrating against NaOH (0.1N) solution until it reaches an end point. Tomato fruit acid content was measured using the equation below:

$$\text{Content of acid (\%)} = \frac{\text{mLs of NaOH used / 0.1N NaOH / correction factor (0.064) / 100}}{\text{Grams of sample}}$$

3.3.3 Total soluble solids (TSS)

Total soluble solids of tomato fruits was determined as described by Nirupama *et al*. (2010) by the use of a digital refractometer (Reed mt-032 brix refractometer-Taiwan) and the values expressed as degree brix. The total soluble solids was obtained by placing a drop of the extracted tomato juice on the refractometer and the percent total soluble solids recorded by reading directly from the refractrometer.

3.4 Statistical analysis

The obtained data was subjected to one-way ANOVA (analysis of variance) using version 20 of the IBM SPSS software at 5% significance level. The significant differences among the samples were determined by the use of the Tukey test. Every measurement was repeated three times with the means and standard deviations stated.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Moisture content

The Moisture content of Assila tomato fruit at its stages of ripening under the two ripening methods (greenhouse and ambient temperature) have been given in Table 4.1. It was observed that the moisture content for tomatoes ripening under greenhouse conditions increased from 91.78% to 95.15%, with the highest moisture content of 95.15% recorded at the full red stage and lowest (91.78%) at breaker.

Table 4.1 Moisture contents of Assila tomato fruit at different stages of ripening under the two ripening conditions

Ripening Stage	Moisture content (%) per ripening methods	
	Greenhouse	Ambient Temperature
Breaker	91.78±0.11a	94.21±0.19a
Turning	94.00±0.55b	94.11±0.29a
Pink	94.67±0.08b	94.56±0.51a
Light red	94.68±0.23b	94.29±0.92a
Full red	95.15±1.58b	94.34±0.51a

Values having similar letters within the same column are not significantly different at 5% significant level

The difference in percent moisture content between harvested tomatoes at breaker stage and at turning stage was significant ($p < 0.05$). The difference in percent moisture content between harvested tomatoes from turning stage to full red stage is however not significant ($p > 0.05$).

From Table 4.1, the moisture content for tomatoes fruits under ambient temperature conditions ranged from 94.11% to 94.56% with the highest (94.56%) moisture content observed at the pink stage and lowest (94.11%) at turning stage. The relatively lower moisture contents for tomatoes

ripening under ambient temperature are in agreement with an experiment conducted by Misbaudeen *et al.* (2009). In their study, they indicated that, the high total solids contents observed (lower moisture contents) for tomatoes ripening under ambient temperature was due to the lack of water supply (irrigation). No significant difference ($p > 0.05$) in percent moisture content was observed among the stages of ripening for the analysis of variance (Table 4.1). The lower percent moisture content in tomatoes ripened at ambient temperature, suggests a higher content of crude fibres, organic matter and minerals (Davies *et al.,* 1981). This makes the ambient temperature method of ripening tomatoes an important method for commercial purposes because ambient temperature tomatoes can hold the longest on the supermarket shelf and are able to tolerate rough handling during storage and shipping. In the industry, these tomatoes are known to have a lower rate of shrinkage.

4.2 Weight loss

Table 4.2 shows the percent physiological weight loss of tomato fruit during ripening under greenhouse and under ambient temperature. Weight loss implies a loss of saleable weight and volume (Genanew, 2013). For greenhouse method, tomatoes at the Breaker stage had the highest weight loss (1.33%) and those at the Full Red stage had the lowest weight loss (0.35%). The difference in percent physiological weight loss between fruits at Breaker stage and fruits at Turning stage was significant ($p < 0.05$), for tomato's growing in greenhouse and ambient temperature respectively. This may imply the presence of complex biochemical changes during those stages of growth, also characterized by other qualities such as colour change. There was also no significant difference observed between the breaker stage and light red stage in the Greenhouse and Breaker and pink stage in fruits stored at ambient temperature. Moreover, the difference in percent physiological weight loss between fruits harvested at the turning stage and

pink stage was not significant ($p > 0.05$) for greenhouse tomatoes. Therefore for this, Assila variety of tomatoes tends to lose a lot of moisture during the breaker stage, compared to the other stages, when ripening under ambient temperature or in the Greenhouse.

Table 4.2 Weight loss of Assila tomato fruit at different stages of ripening under the two ripening conditions

Ripening Stages	Percent weight loss (%) per ripening methods	
	Greenhouse	Ambient Temperature
Breaker	1.33±0.38b	1.58±0.23b
Turning	0.47±0.14a	0.50±0.16a
Pink	0.43±0.12a	0.80±0.11ab
Light red	0.93±0.26ab	0.73±0.16a
Full red	0.34±0.10a	0.35±0.12a

Values having similar letters within the same column are not significantly different at 5% significant level

For tomatoes detached from parent plant and allowed to ripen under ambient temperature, the physiological weight loss ranged from 0.35% to 1.58% during ripening with the highest loss (1.58%) observed at the Breaker stage and the lowest loss (0.35%) observed at the Full Red stage (Table 4.2).

According to Rathore *et al*. (2007), physiological weight loss results from biochemical activities like respiration together with transpiration of water through peel tissue (Rathore *et al*., 2007). Genanew (2013) reported that, weight loss is brought about as a result of water lost from the fruit. More so, Rathore *et al*. (2007) reported that, the water lost may be caused by factors such as temperature and relative humidity of storage, thickness of the peel and surface area volume ratio of the fruit. Several researchers have confirmed transpiration as the main reason for weight loss in tomato produce (Zhiguo *et al*., 2011, Bhattara and Gautam, 2006). Transpiration accounts

for about 92-97% of the weight loss. Hence, the significantly ($p < 0.05$) lower weight loss in greenhouse tomatoes was attributed to lower rate of transpiration which resulted in fewer loss of water. The high loss of weight observed in tomatoes detached from the parent plant and allowed to ripen under ambient temperature may be due to metabolic stress (Zhiguo *et al*., 2011), which reduces the storage life of the tomato fruit. The lower percent of weight losses observed for tomatoes ripening on plants in greenhouse indicate that, greenhouse tomatoes can best be recommended for the market.

4.3 Firmness

Results for the Firmness of Assila tomato fruit at different ripening stages under greenhouse and under ambient temperature have been presented in Table 4.3. Firmness of tomato fruits decreased during ripening for both ripening methods. For tomatoes ripening on the plant in the greenhouse, their firmness ranged from 4.77N to 1.61N. Tomatoes harvested at the breaker stage from the greenhouse were more firm (4.77N) than tomatoes harvested at other stages. Tomatoes in their full red stage were less firm (1.61N). According to Bhattara and Gautam (2006), during ripening of a fruit, its middle lamellae becomes weak which results in fruit softening. This may clarify the softening of tomatoes during ripening in both the greenhouse and at ambient temperature. The observed decrease in fruit firmness during ripening may be associated with the degradation of polysaccharides such as pectin (Adedeji *et al*., 2006).

Table 4.3 Firmness of Assila tomato fruit at different stages of ripening stages under the two ripening conditions

Ripening Stage	Firmness (N) per the ripening methods	
	Greenhouse	Ambient Temperature
Breaker	4.77±0.77a	4.28±0.80d
Turning	3.38±0.33ab	3.23±0.21cd
Pink	3.22±0.68bc	2.82±0.25bc
Light red	1.79±0.41cd	1.82±0.50ab
Full red	1.61±0.38d	1.33±0.18a

Values having similar letters within the same column are not significantly different at 5% significant level

The present results is similar to that of Tilahun *et al*. (2013) who observed that mature green tomatoes were firmer than full ripe tomatoes. The difference in firmness among the ripening stages in the greenhouse was significant ($p < 0.05$) and this is in agreement with Tilahun *et al*. (2013). It has been reported that stage of maturity during harvest significantly affects the firmness of tomato fruit (Moneruzzaman *et al*., 2008).

For tomatoes detached from their parent plant and allowed to self-ripe at ambient temperature, their firmness ranged from 4.20N to 1.33N (Table 4.3). Tomatoes harvested at the breaker stage were more firm (4.20N) than tomatoes harvested at other stages. Tomatoes in their full red stage were less firm (1.33N). The difference in firmness among the ripening stages was significant ($p<0.05$). The level of softening of the tomato fruit is attributed to its firmness which is influenced by its stage of maturity during harvest. According to Adedeji *et al*. (2006), fruit firmness is strongly associated with how susceptible the fruit is to physical damaging when harvesting as well as when storing them. The relatively lower values of firmness observed for tomatoes detached from parent plant and allowed to self-ripe under ambient temperature indicate how less firm and susceptible to physical damaging these tomatoes are and this could be

attributed to harvesting and the conditions of storage. Tomatoes ripening on parent plant in greenhouse are not susceptible to any physical damage since detaching were not done; hence it wasn't touched at all.

4.4 Ethylene concentration

Tomato ethylene concentrations at each stage of ripening under the two ripening methods are presented in Table 4.4. For greenhouse tomatoes, ethylene concentration ranged from 0.052ppm to 0.808ppm with the highest ethylene concentration (0.808ppm) observed at the full red stage and the least (0.054ppm) at the pink stage. The differences among the stages of ripening were significant ($p < 0.05$). Also, the difference in ethylene concentration between tomatoes harvested at the pink stage and those at the Light Red stage was not significant ($p > 0.05$).

Table 4.4 Ethylene concentration of Assila tomato fruit at different stages of ripening under the two ripening conditions

Ripening Stage	Ethylene concentration (ppm) per the ripening methods	
	Greenhouse	Ambient Temperature
Breaker	0.271±0.00c	0.241±0.01cd
Turning	0.168±0.01b	0.213±0.03bc
Pink	0.052±0.00a	0.110±0.01a
Light red	0.060±0.00a	0.181±0.00b
Full red	0.808±0.00d	0.257±0.01d

Values having similar letters within the same column are not significantly different at 5% significant level

For tomatoes harvested and stored in ambient conditions, ethylene concentration ranged from 0.110ppm to 0.257ppm with the highest ethylene concentration (0.257ppm) observed at the full red stage and the least (0.110ppm) at the pink stage, just as was observed in that of the greenhouse tomatoes. Analysis of variance showed a significant difference ($p<0.05$) in ethylene

concentration amongst all the fruit ripening stages for the tomatoes stored in ambient temperatures.

According to Lawton (1991), ethylene gas as a natural plant hormone, is known to promote ripening in very small amounts and modify plant growth. Analysing the internal ethylene concentration at harvest can be used to predict the potential storage and shelf life of fruits and also to determine fruit optimum harvest date (Dilley, 1980). The highest ethylene concentration (0.808ppm) observed at the Full Red stage for greenhouse tomatoes and their short period of ripening after transplanting to reach the Full Red stage (Table 3.1), indicate how fast ripening takes place in the greenhouse and this could be attributed to a shorter shelf life for these tomatoes. It can be predicted that, tomatoes ripening under ambient temperature will have a relatively longer shelf life since ethylene concentrations recorded were steadier throughout the ripening stages and lower at the full red stage. Tomatoes at the full ripe stage could be used to induce ripening in unripe fruits due to the high ethylene concentration. However, if ripening is not desired and longer shelf life is required, the full ripe stage is not to be mixed with the other stages.

According to Pech *et al.* (1992), very low and very high temperatures, flooding or drought, attack by pathogens, heavy metals, treatments with other hormones and wounding are the different types of stress that synthesizes ethylene gas. Some of these factors may have accounted for the high ethylene concentration in the full red tomatoes harvested from the greenhouse. By stimulating many fruits ripening, ethylene improves their appearance. Higher quality fruits can be produced due to rapid changes in the characteristic colour, since less time will have elapsed from harvest for anabolic reactions to occur (VanDen Berg *et al.*, 2000). According to Lawton (1991), both beneficial and harmful effects can occur on fresh fruits due to the presence of

ethylene. He reported that, the harmful effects may include initiating the ripening of stored pre-climacteric fruit, softening of some fruit flesh, flower closure and abscission, yellowing of cucumber and squash, chlorosis, russet spotting of lettuce, toughening of asparagus, bitterness in carrots and leaf abscission.

4.5 pH

According to Gordon *et al*. (2011), pH of a fruit is an essential quality characteristics of its processing. Table 4.5 shows the pH of tomato fruits during ripening at different stages under different ripening methods. For greenhouse tomatoes the highest pH (4.59) was observed at the breaker stage while the lowest pH (4.21) observed at the full red stage. The pH values ranged from 4.21 to 4.59 during ripening.

Table 4.5: Changes in pH of Assila tomato fruit at different stages of ripening under the two ripening conditions

Ripening Stage	pH of tomato fruits per the ripening methods	
	Greenhouse	Ambient Temperature
Breaker	4.59a±0.01a	4.45±0.02a
Turning	4.39b±0.06b	4.35±0.01b
Pink	4.46b±0.01b	4.34±0.01b
Light red	4.43b±0.03b	4.34±0.01b
Full red	4.21a±0.02c	4.11±0.01c

Values having similar letters within the same column are not significantly different at 5% significant level

For tomatoes detached from parent plant and allowed to ripe under ambient temperature, the pH values decreased during ripening, ranging from 4.45 to 4.11 with the highest pH (4.45) observed at the breaker stage and the lowest pH (4.11) observed at the full red stage. Significant difference ($p<0.05$) was observed between tomatoes harvested at the Breaker stage and tomatoes at Turning

stage also between fruits at light red stage and full red stage. There was no significant difference ($p > 0.05$) in pH among fruits harvested from turning stage to light red stage.

The higher and lower pH values observed for greenhouse tomatoes at the Breaker stage and Full Red stage respectively was in agreement with the experiment conducted by Misbaudeen *et al*. (2009). The difference in tomato pH among the stages of ripening was significant ($p < 0.05$). This agrees with the study conducted by Tilahun *et al*. (2013) which revealed that tomato pH value varies significantly at different maturity stages. For both greenhouse and ambient temperature ripening, the difference in pH between fruits at Breaker stage and fruits at Turning stage was significant ($p < 0.05$). The differences in pH value between tomatoes harvested from the Turning stage to Light Red stage is however, not significant ($p>0.05$).

The change in pH values agrees with the study by Misbaudeen *et al*. (2009) who observed an irregular trough-crest manner in pH changes during ripening. Lower values of pH (Table 4.5) that was observed at the various stages of ripening of the tomatoes detached from their parent plant and allowed to ripen under ambient temperature suggest high acidity which correlates with the total tomato flavour as Kader *et al*. (1978) reported. Tomatoes at their Full Red stage at ambient temperature will probably be less sweet since low pH value (high acidity) according to Kader *et al*. (1978) correlates with sweetness.

Primarily, the safety of a fruit is determined by its pH which is also based on the fruit acid contents. According to Anthon *et al*. (2011), to ensure food safety, pH of 4.25 should be the optimum target. The maximum pH value desirable for safety is 4.4. From Table 4.5, only tomatoes at the turning stage were within this range. Georgelis *et al*. (2002) suggested that lower

pH values where it can no longer influence taste can be used for breeding cultivars of tomato purposely for the industry.

4.6 Titratable acidity (TA)

The changes in Titratable acidity of Assila tomato fruit at different stages of ripening under the two ripening methods are shown in Table 4.6. The highest (0.67) TA (citric acid) of tomatoes was observed at the light red stage and the lowest (0.40) at both the breaker and full red stage for greenhouse ripening method. The titratable acidity ranged from 0.40 to 0.67 in tomatoes stored in the greenhouse. The differences in TA among the ripening stages was significant ($p<0.05$).

Table 4.6 Changes in Titratable acidity of Assila tomato fruit at different stages of ripening under the two ripening conditions

Ripening Stage	Tritable acidity of tomato fruits per the ripening methods	
	Greenhouse	Ambient Temperature
Breaker	0.40±0.02a	0.54±0.01a
Turning	0.65±0.01c	0.62±0.03b
Pink	0.58±0.04b	0.70±0.01c
Light red	0.67±0.02c	0.62±0.01b
Full red	0.40±0.02a	0.94±0.01d

Values having similar letters within the same column are not significantly different at 5% significant level

For tomatoes stored in ambient temperature, the Titratable acidity increased during ripening, ranging from 0.54 to 0.94 with highest (0.94) TA (citric acid) observed at the full red stage and the least (0.54) at the breaker stage. The differences in titratable acidity among the stages of ripening were significant ($p < 0.05$).

Titratable Acidity is an approximation of the Total Acidity of a solution (Gordon *et al*., 2011). The titratable acidity is an important factor used to determine the unusual sensory profile of a tomato fruit (Pagliarini *et al*., 2001). Not a simple trend was observed for the TA changes for

both ripening methods as previously reported by Davies *et al*. (1981). The increase in titratable acidity during ripening for ambient temperature condition was however; in agreement with the study of Moneruzzaman *et al*. (2008) who found out that, matured fruit has higher acid content as compared to the immature fruit. During ripening, the increase in total titratable acidity (organic acid in the fruits) may be associated with metabolic processes in living tissues (Tilahun *et al*., 2013).

The reduction in the desirable quality of a fruit may occur as a result of the rapid decrease in the acidity content during fruit ripening (Helyes *et al*., 2006). Therefore, tomatoes detached from parent plant and allowed to ripen under ambient temperature could be of good quality since an increase in content of acidity during ripening was observed in this study (Table 4.6). Oxidation of organic acid to sugar may account for the rapid depletion of titratable acidity observed for greenhouse tomatoes during ripening (Genanew, 2013). For best flavour, high acids and relatively high sugars are required (Stevens *et al*., 1977). There is therefore the need to control rapid decrease in titratable acidity, since the interaction of the total soluble solids and the acid in the fruit are the key component of flavour intensity in tomato fruit, sourness and sweetness which also affect the acceptability of the fruit (Genanew, 2013).

4.7 Total soluble solids (TSS)

Table 4.7 shows the changes in total soluble solids of the tomato fruits at different ripening stages under two ripening methods. It was observed that the total soluble solids for tomatoes ripening on the plant in the greenhouse increased during ripening, ranging from 2.64°Brix to 4.73°Brix with the highest (4.73°Brix) total soluble solids observed at the light red stage and least (2.64°Brix) at breaker stage.

Table 4.7. Total Soluble Solids of Assila tomato fruit at different stages of ripening under the two ripening conditions

Ripening Stage	TSS (^{o}Brix) of tomato fruits per ripening methods	
	Greenhouse	Ambient Temperature
Breaker	2.64±0.04a	3.53±0.04a
Turning	4.50±0.01b	4.40±0.01b
Pink	4.53±0.02bc	4.85±0.01d
Light red	4.73±0.02d	4.62±0.01c
Full red	4.57±0.01c	4.93±0.01e

Values having similar letters within the same column are not significantly different at 5% significant level

These results were in agreement with that of Getinet *et al*. (2008) where they observed that the lowest total soluble solids was for tomatoes harvested at their green matured stage. Also, the highest total soluble solids for tomatoes were observed at the Light Red stage. Differences in total soluble solids among the stages of ripening were significant ($p < 0.05$). This was in agreement with Moneruzzaman *et al*. (2008) who found that, the TSS content of tomato juice varied significantly for all maturity stages. Total soluble solids is an important factor for determining the quality of most fruits. According to Kumar *et al*. (1993) tomato of high quality has TSS between 4.80 and 8.80%.

The TSS for tomatoes detached from parent plant and allowed to self-ripe under ambient temperature increased during ripening, ranging from 3.53^{o}Brix to 4.93^{o}Brix with the highest (4.93^{o}Brix) TSS observed at the full red stage and least (3.53^{o}Brix) at breaker stage. Similar results were observed by Tilahun *et al*. (2013) who recorded the highest value of TSS at the Full Red stage whereas green matured fruits had lower TSS value.

The results from the study indicate a general increase in total soluble solids during ripening. This was in line with a study by Helyes *et al*. (2006), who reported that, fruit total soluble solids increases during its ripening. The conversion of starch to sugar during ripening and also the loss of water during storage may be responsible for the increase in total soluble solids of a fruit when ripening. These may lead to higher concentrations of polysaccharides in the fruit (Genanew, 2013). Salunkhe *et al.* (1993) reported that fruit development increases with increase in soluble solids content through a biosynthesis process such as the degradation of polysaccharides. Casierra-Posada *et al*. (2007) also suggested that the increasing trend in total soluble solids content could be attributed to the accumulation of lower total soluble solids in the earlier stages of development which could have occurred in this study. Based on the findings of a study conducted by Borji *et al.* (2012), they suggested that for the achievement of optimal yield, medium or full ripe stage of ripening will be suitable for harvesting.

According to Helyes *et al*. (2006), the interaction of the total soluble solids and the acid are responsible for tomato flavour intensity, sourness and sweetness. Hurr *et al*. (2005) also reported that, the production of complex volatiles and the buildup of organic acids and sugars in the vacuoles resulted in flavour development, fruit taste and aroma.

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATIONS

5.1 CONCLUSION

Tomato postharvest quality can be affected by several factors. One of the key factors that plays an important role in tomato quality is the stage of ripening at harvest. From the study conducted, the percent moisture content of Assila tomato during ripening initially ranged from 91% to 94% and finally increased to about 95%. There was a decline and an increase in titratable acidity (TA) values for greenhouse tomatoes (0.67 to 0.40) and for ambient temperature respectively (0.54 to 0.94), and an increase in Total Soluble Solids (TSS) content for both ripening method (2.64 to 4.73 for greenhouse and 3.53 to 4.93 for ambient temperature) as ripening stages advanced. Fruit pH decreased during ripening which corresponds with an increase in tomato TA. At the various ripening stages, the tomato pH in association with its TSS and TA ensures a good quality of tomato fruit required by the consumer. Ethylene concentration ranged from 0.052ppm to 0.808ppm and 0.110ppm to 0.257ppm for greenhouse and storage at ambient temperature, respectively. The lower ethylene concentrations observed in this study indicate that, harvested Assila tomato fruits at their green matured stage can be transported to the market for longer distances. In general, the physiological and physicochemical changes were influenced by the different ripening conditions.

5.2 RECOMMENDATIONS

- Further research could be done to study the effect of greenhouse and ambient temperature on the physiological and physicochemical changes during ripening of other local cultivars of tomato in Ghana.

- Economic analysis of the use of ambient temperature method for ripening of tomato fruits should be conducted to assess the profitability of its use.

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APPENDICES

Appendices 1. Tables of analysis of variance for Greenhouse method

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
MC	Between Groups	21.484	4	5.371	9.348	.002
	Within Groups	5.746	10	.575		
	Total	27.230	14			
PWL	Between Groups	2.108	4	.527	10.502	.001
	Within Groups	.502	10	.050		
	Total	2.609	14			
FIRM	Between Groups	20.124	4	5.031	17.102	.000
	Within Groups	2.942	10	.294		
	Total	23.066	14			
EC	Between Groups	1.174	4	.294	13106.626	.000
	Within Groups	.000	10	.000		
	Total	1.175	14			
PH	Between Groups	.222	4	.056	61.715	.000
	Within Groups	.009	10	.001		
	Total	.231	14			
TA	Between Groups	.202	4	.050	84.122	.000
	Within Groups	.006	10	.001		
	Total	.208	14			
TSS	Between Groups	9.107	4	2.277	5097.366	.000
	Within Groups	.004	10	.000		
	Total	9.112	14			

Appendices 2. Tables of analysis of variance for Ambient temp. method

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
MC	Between Groups	.343	4	.086	.288	.879
	Within Groups	2.986	10	.299		
	Total	3.329	14			
PWL	Between Groups	2.743	4	.686	7.300	.005
	Within Groups	.939	10	.094		
	Total	3.682	14			
FIRM	Between Groups	16.414	4	4.103	19.843	.000
	Within Groups	2.068	10	.207		
	Total	18.482	14			
EC	Between Groups	.040	4	.010	64.026	.000
	Within Groups	.002	10	.000		
	Total	.042	14			
PH	Between Groups	.181	4	.045	322.667	.000
	Within Groups	.001	10	.000		
	Total	.182	14			
TA	Between Groups	.285	4	.071	334.172	.000
	Within Groups	.002	10	.000		
	Total	.287	14			
TSS	Between Groups	3.829	4	.957	3339.267	.000
	Within Groups	.003	10	.000		
	Total	3.832	14			